IFPRI

RESEARCH REPORT 113

A Meta-Analysis of Rates of Return to Agricultural R&D

Ex Pede Herculem?

Julian M. Alston
Connie Chan-Kang
Michele C. Marra
Philip G. Pardey
TJ Wyatt

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI) is one of 16 Future Harvest centers and receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research. IFPRI receives support from the Asian Development Bank, Australia, Belgium, Brazil, Canada, CARE, Centre Technique de Coopération Agricole et Rurale, China, Denmark, the European Commission, Finland, the Ford Foundation, France, the German Agency for Technical Cooperation, the German Federal Ministry for Economic Cooperation and Development, the Helen Keller Foundation, Honduras, India, the Inter-American Development Bank, the International Fund for Agricultural Development, Ireland, Italy, Japan, the John D. and Catherine T. MacArthur Foundation, Malawi, Mexico, Mozambique, the Netherlands, the Neys-Van Hoogstraten Foundation, Norway, the Philippines, the Rockefeller Foundation, Spain, Sweden, Switzerland, the United Kingdom, the United Nations Children's Fund, the United States, the World Bank, and World Vision.

IFPRI Research Reports Publications Review Committee 2000

Recent IFPRI Research Reports

The International Food Policy Research Institute (IFPRI) was established in 1975 to identify and analyze alternative national and international strategies and policies for meeting food needs of the developing world on a sustainable basis, with particular emphasis on low-income countries and on the poorer groups in those countries. While the research effort is geared to the precise objective of contributing to the reduction of hunger and malnutrition, the factors involved are many and wide-ranging, requiring analysis of underlying processes and extending beyond a narrowly defined food sector. The Institute's research program reflects worldwide collaboration with governments and private and public institutions interested in increasing food production and improving the equity of its distribution. Research results are disseminated to policymakers, opinion formers, administrators, policy analysts, researchers, and others concerned with national and international food and agricultural policy.

All manuscripts submitted for publication as IFPRI Research Reports undergo extensive external and internal reviews. Prior to submission to the Publications Review Committee, each manuscript is circulated informally among the author's colleagues, presented in a formal seminar, and reviewed by an IFPRI reviewer. Following submission of the manuscript to the Committee, three additional reviewers—at least two external to IFPRI and one from the Committee—are selected to review the manuscript. Reviewers are chosen for their familiarity with the country setting. The Committee provides the author its reaction to the reviewers' comments. After revising as necessary, the author resubmits the manuscript to the Committee with a written response to the reviewers' and Committee's comments. The Committee then makes its recommendations on publication of the manuscript to the Director General of IFPRI. With the Director General's approval, the manuscript becomes part of the IFPRI Research Report series, which began in 1977.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
2033 K STREET, N.W., WASHINGTON, D.C. 20006-1002 U.S.A.
PHONE: 1-202-862-5600 • FAX: 1-202-467-4439
E-MAIL: ifpri@cgiar.org • WEB: www.ifpri.org

A Meta-Analysis of Rates of Return to Agricultural R&D

Ex Pede Herculem?

Julian M. Alston

Connie Chan-Kang

Michele C. Marra

Philip G. Pardey

TJ Wyatt

International Food Policy Research Institute
Washington, D.C.

A Meta-Analysis of Rates of Return to Agricultural R&D

Ex Pede Herculem?

Julian M. Alston

Connie Chan-Kang

Michele C. Marra

Philip G. Pardey

TJ Wyatt

IFPRI

International Food Policy Research Institute
Washington, D.C.

To Willis Peterson, who passed away during the production of this report. Willis was a pioneer in the economic analysis of agricultural research and technical change, a teacher, and an inspiration—as well as a friend and a good bloke.

About the subtitle: From a part (literally “from the foot of Hercules”), can we judge the whole?

Library of Congress Cataloging-in-Publication Data

A meta-analysis of the rates of return to agricultural R & D : ex pede herculem? / Julian M. Alston . . . [et al.].
p. cm. — (Research report ; 113)
Includes bibliographical references (p.).
ISBN 0-89629-116-2 (paperback)
1. Agriculture—Research—Economic aspects. 2. Agriculture—Research—Evaluation. 3. Rate of return. I. Alston, Julian M. II. Research report (International Food Policy Research Institute) ; 113.

S540.E25 M47 2000
338.1′4—dc21 00-040733

Contents

Tables

Figures

Foreword

IFPRI has long argued that spending on agricultural research constitutes a sound investment in poverty reduction and agricultural and economic growth, through improvements in productivity. This argument is based partly on the reported evidence of high rates of return to agricultural research, typically believed to be in the range of 40–60 percent per year. Yet there continues to be controversy over whether these figures are to be believed, and over what they actually indicate. This study represents the first attempt to take a comprehensive look at all the available evidence on rates of return to investments in agricultural R&D since 1953, and the only attempt to do so in a formal statistical fashion.

The average reported rate of return is much higher than is commonly understood, and the range is much greater. Some systematic patterns emerge. For example, rates of return to research may be higher when the research is conducted in more-developed countries. Rates of return also vary by problematic focus—returns were lower for research on commodities with longer production cycles, for instance—and with the characteristics of the research evaluation itself. In addition, the report shows that there is no evidence to support the view that rates of return have declined over time.

This report has compiled and documented the literature in ways that make it more accessible and more useful to other researchers and policymakers, as well as others interested in the evidence. The analysis reveals some systematic patterns and some sources of biases that make it easier to interpret the evidence and draw meaningful conclusions.

Per Pinstrup-Andersen
Director General

Acknowledgments

The authors are listed alphabetically, and senior authorship is not implied. Special thanks are due to Cameron Alston, Mary-Jane Banks, Susan Casement, and Tricia Klosky for help with bibliometric aspects of the study and tracking down additional reference materials. We are grateful to Princeton Editorial Associates and to Heidi Fritschel of IFPRI for editorial assistance.

The authors also thank Flavio Avila, Harry Ayer, Cynthia Bantilan, Jeff Davis, Bob Evenson, Glenn Fox, Dely Gapasin, Mahabuh Hussain, Aida Librero, Luis Macagno, Will Masters, George Norton, Jim Oehmke, Peter Pee, Prabhu Pingali, John Sanders, Colin Thirtle, and Tom Walker for providing published material we requested, sometimes on short notice. In addition thanks are extended to Jerry Carlson, Rob Dumsday, Jenni James, Alain de Janvry, Kerry Smith, Tom Walker, Stan Wood, and anonymous reviewers, as well as participants at workshops at IFPRI, North Carolina State University, and the Australian Agricultural and Resource Economics Society Conference at Christchurch (1999), for providing helpful comments and suggestions.

We are grateful for partial support from the Technical Advisory Committee for the Consultative Group on International Agricultural Research (CGIAR-TAC), the U.S. Agency for International Agricultural Development (USAID, Global Bureau), and the University of California Pacific Rim Program.

This report was prepared by the Global and Regional Program on Science and Technology Policy at the International Food Policy Research Institute, Washington, D.C., in collaboration with the Science and Technology Program of the University of California Agricultural Issues Center, Davis, California.

Summary

Conventional wisdom is that investments in agricultural R&D have yielded handsome dividends for society, more than enough to justify past investments and to support increased funding in the future. Many cite annual rates of return in the range of 40–60 percent as the norm, although some have suggested that these estimates are biased upwards or represent a partial and possibly biased sample of the overall rate-of-return evidence.

Past reviews of the evidence on rates of return to agricultural research have been generally descriptive in nature, usually ad hoc, and always partial. The entire body of work has not been subjected to systematic, quantitative scrutiny of the types needed if we were to adequately answer various questions that have relevance to decisionmakers concerned with agricultural R&D. For example, do the returns to more recent investments match those of investments in earlier times; do investments in international R&D yield greater payoffs than investments in research conducted by national agencies; is there any evidence to support the view that research into crops yields higher rewards than livestock research? To interpret the empirical evidence properly also requires answers to some more subtle but equally important questions concerning the consequences of varying estimation techniques for the measured rates of return. Different studies in different locales at different time periods have used different evaluation methods. Do these differences in methods have implications for the interpretation of the evidence? Do some methods lead to a bias, a systematic difference between the actual and the measured rate of return?

In this study we made a concerted effort to assemble all the available evidence on the returns to investments in agricultural R&D published since 1953. This was the publication year of the seminal study by Nobel laureate T. W. Schultz, who first introduced an economic approach to assessing the impacts of agricultural R&D. We searched comprehensively for all the subsequent literature, be it studies published in refereed journals or in less formal forms like book chapters, monographs, and discussion papers. We assembled 292 studies reporting a total of 1,886 rate of return estimates—an average of 6.5 estimates per published study. About one-third of the publications were in refereed journals.

Few (21 percent) of the published rate of return estimates fall within the range of conventional wisdom of 40–60 percent per year. Excluding two extreme outlier observations (724,323 and 455,290 percent per year), the average rate of return was 100 percent per year for research, 85 percent for extension, 48 percent for studies that estimated the returns to research and extension jointly, and 81 percent for all the studies combined. However, these averages give an incomplete and in some important ways misleading picture.

The rate of return estimates are widely dispersed around their respective averages. For example, studies of returns to research reported estimates of annual rates of return ranging from –7.4 percent to 5,645 percent. To demonstrate the effects of skewness on measures of central tendency in the various distributions of estimates of rates of return, we report the mode (the value of the most frequent observation) and median (the central value when observations are arrayed by size), in addition to the mean (or simple average). The median of the rate of return estimates was 48.0 percent per year for research, 62.9 percent for extension studies, 37 percent for studies that estimated the returns to research and extension jointly, and 44.3 percent for all studies combined. This is almost half the corresponding average, indicating significant positive skewness in the distribution of rates of return.

What accounts for the substantial variation in the reported rates of returns? We posited a number of factors, grouped into four broad categories:

- Characteristics of the rate of return measure (for example, real versus nominal measures, ex post versus ex ante, average versus marginal, private versus social)
- Characteristics of the analysts performing the evaluation (factors intended to reveal possible bias or differences in precision of the measures associated with the attributes of the person or group that generated the estimate, or differences in the methods and approaches used that are not revealed by our other proxies)
- Characteristics of the research being evaluated (for example, the field of science, commodity class, type of technology, time period and geographical location, and institutional scope of the research being evaluated)
- Features of the evaluation (details of the methodologies used to estimate the returns to research, like the structure and length of the lag between R&D spending and its productivity consequences)

Some of these factors cause variation in the underlying, true rate of return, some affect only the measurement of that true effect, and others influence both the true rate of return and its measurement. Because of the importance of within-group variability, it was difficult to draw meaningful inferences from tabulations and simple pairwise comparisons. Thus, to identify not only the significance but also the magnitude of the effect of a particular factor on the reported rate of return, we used multiple regression techniques in a meta analysis of the rates of return evidence. To construct our meta–data set, all the rate of return studies were assigned an identification number and then scored according to characteristics deemed likely to influence the true or measured returns to R&D. Using statistical methods to discard extreme outliers that would unduly influence the analysis, and dropping 726 observations because of missing values for one or more of the characteristics and a further two extreme observations, left us with 1,128 observations in our regression analysis.

We found no evidence to support the view that the rates of return have declined over time, but our results suggest that returns may be higher when the research is conducted in more-developed countries. The returns varied by problem focus, with lower rates of return for research on commodities and natural processes with longer production cycles. Characteristics of the research being evaluated matter—specifically, the measured rates of return were lower when the scope of the research being evaluated was broader and when studies measured the rate of return to research and extension jointly, compared with research only. Characteristics of the research evaluation matter too. In particular, in econometric studies, large rates of return were associated with truncated research lags. We could identify no effect of accounting for R&D spillovers or market distortions on measured rates of return.

Our key finding is that the sample averages or representative ranges stressed by previous reviews reveal little meaningful information about the rate of return evidence. We show that the rate of return literature and the numerous rate of return estimates in that literature have a low signal-to-noise ratio that does not lend them to meaningful analysis by ad hoc inspection. Nonetheless, our formal meta-analysis using multiple regression techniques does reveal some systematic sources of variation in the rate of return to R&D that should prove useful to policymakers.

CHAPTER 1

Introduction

Agricultural science administrators and those to whom they answer have long been interested in measures of the economic benefits from agricultural research and development (R&D). McMillen's (1929:141) account of the first known attempt to evaluate U.S. agricultural R&D illustrates some issues that have continued to plague the endeavor:

> During the last of his three notable terms as Secretary of Agriculture, "Tama Jim" Wilson directed his bureau chiefs to compile a report that would provide a picture of what, if any, profit could be shown to the country on the expenditures for research through the Department of Agriculture.
>
> Careful studies accompanied the compilation of the report. Numerous interests and industries were asked to estimate conservatively the value of such of the department's findings as affected their operations. Finally the expenditures were totaled in one column, the estimates of the returns in another, and the sheets placed before the venerable secretary.
>
> "This will never do!" he protested. "No one will swallow these figures!"
>
> The report revealed that for every single dollar that had been spent for scientific research in the Department of Agriculture, the nation was reaping an annual increase of nearly a thousand dollars in new wealth.
>
> "Cut it down to $500," insisted Wilson. "That's as much as we can expect the public, or Congress, to believe."

The more recent literature has its roots in work by Schultz (1953) and Griliches (1957). Since then hundreds of studies have reported measures of the returns to agricultural R&D. These studies potentially provide a rich source of information, but only limited advantage has been taken of this potential. Some partial periodic tabulations (see Evenson, Waggoner, and Ruttan 1979; Echeverría 1990; Alston and Pardey 1996) have been made, but to date no one has characterized and synthesized this literature in ways that reveal interesting and useful patterns in the rate of return estimates; nor have these estimates been subject to any critical, quantitative evaluation.

Pulling together this body of work and subjecting it to systematic, quantitative scrutiny can help answer a range of questions that are of direct importance to international and national decisionmakers concerned with agricultural R&D. Common questions include the following:

- Has the rate of return to agricultural R&D declined over time?
- Do the returns to agricultural R&D differ internationally (a) among regions of the world (say, between Asia, Africa, and Latin America), (b) between developing and developed countries, or (c) between national agricultural research systems and international centers?
- Does the return to research vary according to its problematic focus (for example, between crop and livestock research or among different crops), and how does the rate of return to environmental or natural resource research compare with the rate of return to more traditional agricultural production R&D?
- Does the rate of return vary between basic and more applied research, or between research and extension?
- Is systematic bias built into the estimates from particular evaluation techniques and estimation details, from other aspects of the analysis, or according to who performs the analysis (for example, self-analysis versus external evaluation)?

Our aim in this project has been to systematically analyze the literature on the returns to agricultural R&D in ways that provide insights into these questions, and to communicate the results in a way that is meaningful for both noneconomists and economists. We compiled a comprehensive collection and listing of the empirical literature on the rate of return to agricultural R&D (including both published articles and reports, and unpublished "gray" literature). This collection comprises 292 studies that provided quantitative estimates of returns to research that were suitable for analysis. Moreover, many of the studies provide more than one estimate of a rate of return to research, so the database for analysis comprises 1,886 observations, of which 1,128 were suitable for multivariate regression analysis.

To help the reader understand the reasons for this study, and why particular questions are being emphasized, Chapter 2 discusses briefly why this study is needed, what we hoped to achieve in it, and its scope. Issues raised here include (1) recent trends in funding for agricultural R&D, and the value of information about returns to research in providing support for sustained funding; (2) questions about the allocation of research resources among different institutions, projects, and fields of science, and the usefulness of information on returns to R&D in guiding those decisions; and (3) the benefits from a comprehensive, comparative assessment of the entire field of work as a basis for interpreting the results and using them to guide the total allocation of resources to agricultural R&D, and the further allocation of that total within agricultural R&D. This discussion leads, naturally, into one of meta-analysis, which is designed to enable such a comprehensive assessment. The chapter concludes with a brief consideration of the scope of the study.

In Chapter 3 we provide a summary of the economic concepts that underpin the economic measures of returns to investments in research. This chapter defines the internal rate of return (IRR) and provides a conceptual foundation for its use as a measure of research impact, also addressing the applicability of other measures of research impact. At the end of this chapter the reader should come to appreciate why the economic measures are appropriate, and that the IRR is an appropriate representation of the social profitability of projects. In Chapter 4 we discuss the measurement issues that arise in empirical research impact assessment, and how certain aspects of the analysis can influence the resulting estimates of rates of return. This discussion leads to the development, in Chapter 5, of some hypotheses or conjectures about how the estimated IRR may vary systematically with certain characteristics of the analyst, the study methods, or the research enterprise or activity being studied.

From the theoretical discussion in Chapters 3–5 we proceed to empirical work in Chapters 6 and 7. Chapter 6 documents and tabulates summary statistics, describing the nature of the studies and their results in what we hope is an informative way. In order to develop this data set, we reviewed all the relevant papers and scored each estimate according to

- Characteristics of the *measure* of the rate of return (for example, real versus nominal, marginal versus average, private versus social, reported in the study versus deduced by us),
- Characteristics of the *analyst,* sometimes defined by the characteristics of the author(s) of the study (for example, author name(s), institutional affiliation(s), and whether the study was a self-evaluation),
- Aspects of the *research* being evaluated, including its focus (for example, commodity orientation, natural resource focus), the period during which the research was performed, the nature of the technology studied (for example, biological, chemical, mechanical) and the R&D (for example, basic, applied, extension), the sector to which it applies (for example, input supply, on-farm, postharvest), its country or regional focus, and the institutional details of the agency doing the research being evaluated (for example, national government, near government, international, private), and
- Characteristics of the *evaluation,* including technical estimation details (for example, the nature of the lag structure, the lag length, the method of estimation, and the treatment of price distortions), as well as when and where the study was published.

The tables and figures in Chapter 6 provide useful information, but these are only partial measures of correlation and conditional means. In order to really understand the consequences of particular characteristics for the rate of return estimates, we must measure the effects of all the variables at the same time in a multivariate analysis. The formal term for this type of analysis is *meta-analysis,* a statistical review of research studies in a particular area of scientific inquiry. Chapter 2 defines meta-analysis, reviews the recent literature and its rising importance, and argues why meta-analysis is needed to make sense of a body of scientific evidence; Chapter 7 reports our application of this relatively new technique to our new data set on returns to agricultural R&D. Chapter 8 concludes the body of the report. The appendix contains a complete listing of the source publications used in the meta-analysis, along with the supporting list of references from which the data set was constructed.

CHAPTER 2

Reasons for the Study

A great deal of effort and money has been spent on assessing the impacts of agricultural R&D. Yet questions persist about what the resulting evidence means, its accuracy, and how it can be used. If impact assessment is to be worthwhile, we must make sense of the results in a way that is meaningful to those empowered to make decisions about the total amount of money to be made available for agricultural research and about how to spend that money. One reason—perhaps the main reason—for conducting benefit-cost analysis of agricultural R&D has been to provide evidence for shoring up support for the agricultural R&D enterprise. Indeed the demand for impact assessment is always highest when the threats to funding are most serious.

Most agricultural economists and other agricultural scientists appear to believe that, in general, public agricultural R&D has paid handsome dividends for society. That is the position most frequently stated, and one rarely hears an opposing view articulated (exceptions include Pasour and Johnson 1982 and Kealey 1996); opponents are more often concerned about distributional effects of socially profitable research (for example: yes, society gains, but farmers in a particular category are made worse off or do not share in the benefits). Even among agricultural scientists, who have a vested interest in the view that what they do for a living is good for the world, there is a range of subjective views about just how profitable the investment in agricultural R&D has been, or will be, for society as a whole.[1] Beyond agricultural scientists, who are relatively well informed about (as well as interested in) the issue, are others who have even more diverse views about the social payoff to research—including some, no doubt, who are convinced that it is evil.

Some of these views are well informed; others are just opinions. Some are strongly held; others are but loosely held. However they may have come about, there does exist a set of prior views about the merit of public investments in agricultural

[1] The idea that R&D is socially profitable is implicit in the modern literature on sources of economic growth, especially in consideration of the new emphasis on interindustry spillovers of research results, which enhance the payoff and exacerbate the market failure in private R&D. A related issue is diminishing returns in R&D.

R&D. We can characterize this as a distribution, in the statistical sense, and consider its central tendency as a "conventional wisdom" about *the* rate of return. What amounts to conventional wisdom may differ systematically among different groups in society. The conventional wisdom of agricultural scientists, based on their information, may be very different from that of others in society; agricultural economists are likely to have based theirs, more than most other groups, on the evidence about rates of return. But the rate of return evidence has probably played a part in defining the entire distribution of opinion, and refining what that evidence means can lead to a shift in the conventional wisdom. Different groups have different views and attach different weights to the record from published studies, and this may help account for what appears to be a paradox: an inconsistency between the economic implications of the general conventional wisdom (largely consistent with the published rates of return) and recent policy developments.

An Apparent Paradox

In recent years, a paradox has become apparent. On the one hand, we have an ever-expanding volume of what appears to be generally consistent evidence that rates of return to public agricultural R&D are high—high enough to justify past support and an even greater investment of public funds. On the other hand, we have seen in recent years in most countries, rich and poor alike, a marked slowdown, if not an actual decline, in public funding for agricultural R&D. Support for international research is dwindling despite seemingly strong evidence that it pays off handsomely.

We can speculate about the causes. One possibility is that the decisionmakers are simply ignorant of the results. Alternatively they may be aware of the rate of return evidence but use the information in different ways. One way to structure the interpretation and use of the evidence is to consider a sequence of binary classifications of outcomes. At the first level, a calculated rate of return may be either HIGH or LOW. Suppose it is HIGH. Then there are two possibilities: the estimate may be TRUE or FALSE. For instance, a FALSE result may have been generated because the procedure was biased by the inadvertent omission of certain relevant expenditures from the cost side (say on private research or extension), by the inappropriately short truncation of the research lags, by the failure to account properly for the effects of market-distorting commodity policies or externalities, or by the understatement of the social opportunity cost of government funds. It could even result from deliberate efforts to bias the analysis toward a favorable result (or toward the "conventional wisdom").

Suppose, however, it is TRUE: the actual rate of return was, in fact, HIGH, implying that public investments should increase if we are to maximize net social welfare. As the accuracy of the calculated rate of return is unknown, perhaps even to the analyst who calculated it, the decisionmaker is left with two options: to BELIEVE or DISBELIEVE the results. We listed previously some of the ways that a FALSE result could be obtained, and in contemplation of any of these the decisionmaker may conclude that we cannot be sure the rate of return is high enough to justify the investment. A decisionmaker who DISBELIEVES the rate of return is likely to choose to NOT-FUND continued research.[2]

A decisionmaker who does BELIEVE that the TRUE social rate of return is HIGH may nevertheless choose to NOT-FUND rather than FUND. Why? One reason is that decisionmakers could have different objectives—objectives other than the maximization of net social welfare—so that a high social rate of return does not necessarily justify more investment to them. For example, a decisionmaker may believe that the appropriate objective of research is to alleviate extreme poverty or to preserve the environment, and high social rates of return may not be deemed to relate closely enough to either of these alternatives.[3] Second, although it is perhaps just the other side of the same coin, decisionmakers have to operate in a political context in which interest groups compete for favor (and, indeed, scientists and administrators of scientific organizations, especially those who conduct or sponsor the research being evaluated, are seen at times as one such group). The evidence of actual policies supports the view that government policy is driven by distributional objectives rather than the simple maximization of national welfare; witness U.S. or European farm commodity programs, for instance.[4] A third possibility is that the decisionmaker believes that the rate of return is high and greater public investments are warranted, but constraints on the availability of public funds force some socially profitable investments to remain unexploited.

Even considering these possible explanations, what appeared at first to be a complete paradox remains something of a contradiction and a puzzle, and this is a primary motivation for the study. In order to make sense of the situation, a first step is to see whether the evidence from the literature really does support the view that the rates of return to research have been high, and to provide more detailed information on which types of research have been the most profitable, with allowance made for the effects of other factors that may have influenced the measured rates of return. Even without the "paradox," the study is worthwhile as a clarification of the evidence from the past, so that it can be more useful for guiding decisions that will affect the future. Indeed if the explanation is that the results have not been credible, or have not been fully understood, then this study may help bring about a closer correspondence between the evidence and the policy response.

---

[2] The rate of return could be ex post, based on past research, or ex ante, related to some proposed future investment. Thus another possibility is that the decisionmaker may believe that an ex post rate of return to past research was truly high, but that the basis for projecting into the future may be false.

[3] Regardless of what some economists have said about this issue, decisionmakers in charge of research funds do say that they have these other objectives in mind, and not simply maximizing social welfare. This could be interpreted as evidence that the decisionmakers do not really understand the economics—implying, in turn, that economists have not always done a good enough job of making their results meaningful for decisionmakers.

[4] Even so, mounting evidence of high rates of return to agricultural R&D might not be expected to be associated with a decline in public support for agricultural R&D unless something else has changed: either the evidence is being viewed with increasing skepticism or the opportunity cost of other investments is rising (a higher rate of return is perceived for alternative public investments, such as other R&D or education).

Issues in Funding for R&D

As we begin the 21st century, significant changes are taking place in the financial support for agricultural R&D and in the roles played by national and international governments, their agencies, and the private sector. Some of these changes represent a continuation of longer-run trends; others represent dramatic departures from previous patterns.

Worldwide, investments by national governments in public agricultural research almost doubled in real terms, from $7.3 billion (1985 international dollars) in 1971 to nearly $15 billion in 1991 (Table 1).[5] Expenditures on publicly performed agricultural research in developing countries grew by 5.1 percent per year from $3 billion (1985 international dollars) in 1971 to $8 billion in 1991. Across the developed countries, public agricultural spending grew by 2.3 percent per year from $4.3 billion (1985 international dollars) in 1971 to $6.9 billion by 1991.

For all regions of the world, however, real R&D spending grew at a much slower pace during the 1980s than in the 1970s. Pardey, Roseboom, and Craig (1999) summarized the global trends, identifying three main points. First, after a decade of strong growth, the growth in real public investments in agricultural research slowed substantially during the 1980s (from 6.4 percent per year in 1971–81 to 3.9 percent in 1981–91 for developing countries, and from 2.7 percent to 1.7 percent for developed countries). Second, in 1991, developing countries as a group spent more ($8.0 billion 1985 international dollars) than developed countries ($6.9 billion) on public agricultural R&D, a reversal of the relative shares that prevailed only a decade earlier. Third, the real growth rate of investments in international agricultural research by the Consultative Group on International Agricultural Research (CGIAR) slowed from 4.0 percent per year during the 1980s to 0.5 percent per year since 1990.

These shifts in funding patterns have occurred despite claims by economists and others that evidence of high social rates of return justifies ever greater R&D investments. Thus issues are raised about whether the evidence supports those claims, whether it is true or false, whether it is understood and used by decisionmakers or irrelevant, and so on. A further, related set of issues concerns trends in the allocation of the agricultural research budget and the informational basis for these shifts in funding patterns.

---

[5] These "global" totals are preliminary estimates that exclude Eastern European and former Soviet Union countries. The principal data source for the 1961–85 period is Pardey, Roseboom, and Anderson (1991). These data were revised and updated for African countries using the data and reference material reported in Pardey, Roseboom, and Beintema (1997) for most of the principal Asian countries (including China and India) with data from Pardey, Roseboom, and Fan (1998), and for the developed countries with data from Pardey, Roseboom, and Craig (1999). See also Alston, Pardey, and Roseboom (1998). Semiprocessed data from numerous other sources were obtained for most of the mid- to larger-sized national agricultural research systems and a number of smaller systems. The developing countries for which we have direct estimates account for approximately 85 percent of the developing country total.

Table 1—Public agricultural research expenditures and average annual growth rates, global trends

Parameter	1971	1981	1991
	(millions of 1985 international dollars)[a]		
Expenditures			
Developing countries (131)[b]	2,984	5,503	8,009
Sub-Saharan Africa (44)[b]	699	927	968
China	457	939	1,494
Asia and Pacific, excluding China (28)[b]	861	1,922	3,502
Latin America and Caribbean (38)[b]	507	981	944
West Asia and North Africa (20)[b]	459	733	1,100
Developed countries (22)[b]	4,320	5,744	6,956
Global total (153)[b]	7,304	11,247	14,966
	1971–81	**1981–91**	**1971–91**
	(percentage)		
Average annual growth rates			
Developing countries	6.4	3.9	5.1
Sub-Saharan Africa	2.5	0.8	1.6
China	7.7	4.7	6.3
Asia and Pacific (excluding China)	8.7	6.2	7.3
Latin America and Caribbean	7.0	–0.5	2.7
West Asia and North Africa	4.3	4.1	4.8
Developed countries	2.7	1.7	2.3
Global total	4.3	2.9	3.6

Source: Pardey, Roseboom, and Craig (1999:56).

Note: The 153 countries included in these totals correspond to the coverage reported in the appendix tables in Pardey, Roseboom, and Anderson (1991). Notably countries from the former Soviet Union and eastern Europe are excluded, but here we include South Africa.

[a] Research expenditures denominated in current local currency units are first deflated to 1985 prices using local implicit GDP deflators taken from World Bank (1995) and then converted to international dollars (where one international dollar is set equal to one U.S. dollar) using the purchasing power parities taken from Heston et al. (1995).

[b] Figures in parentheses indicate the number of countries in the respective aggregate.

Issues in Research Resource Allocation

Alston, Pardey, and Smith (1999) document recent changes in agricultural research institutions and investments in five Organization for Economic Cooperation and Development (OECD) countries (Australia, the Netherlands, New Zealand, the United Kingdom, and the United States) in detail, and the chapter in that volume by Pardey, Roseboom, and Craig (1999) provides an overview for the OECD as a whole.

These studies found that, as discussed previously, developed countries have shifted markedly toward more private funding of agricultural R&D and increased private provision of agricultural R&D, with private agricultural R&D totaling $7 billion (1985 international dollars) in the OECD—about half the public and private total. They document that public sector roles have been changing in response to a slowing of the growth in public support for research in general and agricultural research in particular, pressures for increased accountability for the use of public R&D funds, and a broadening of the agricultural research agenda to include issues such as food safety, quality, and convenience. In addition, both private and public research agencies have had to adapt to deal with increased concerns about the environmental consequences of agriculture and of new agricultural technologies, sizable shifts in the biotechnologies that underpin the agricultural sciences, and a strengthening of the intellectual property protection afforded new agricultural know-how, research tools, technologies, and crop varieties developed by scientists or discovered in farmers' fields.

Need for Comprehensive Assessment of the Evidence

The changing patterns of total funding support for public sector agricultural R&D might reflect a growing skepticism about the evidence that the rate of return to agricultural R&D has been high, or about what that evidence implies about the appropriate rate of investment. In our own experience at least, we have noticed a growing number of agricultural economists expressing some doubts about the evidence and what it means. But most such comments are based on very limited information—a glimpse of the tip of the iceberg. A comprehensive assessment of what the past studies have actually said is a necessary first step before we pass judgment on what the record means. Going beyond a simple summary requires an evaluation and an assessment of the differences in findings among studies and a sense of why they differ.

In addition to changes in overall support for agricultural R&D, in recent years we have witnessed some significant shifts in patterns of support within the agricultural R&D portfolio. Public agricultural R&D portfolios in many countries have been shifting, we are told, toward more basic research and away from the so-called "near market" or applied research areas and extension; away from agricultural commodity research areas (such as crop improvement) and toward R&D related to the environment, natural resource management, or value-adding; away from traditional agricultural R&D and generally toward modern biotechnology; and so on.

These shifts have often been motivated by, or justified in terms of, market failure arguments and an implicit belief that the rate of return to the portfolio will be increased as a result of the redirection of the funds. But such perspectives are typically based more on prejudice or in-principle theoretical arguments alone and are rarely supported by any empirical evidence about the relative rates of return. Economists are partly to blame. They have failed to provide convincing evidence on the comparative rates of return to different types of public R&D investments in forms that make them useful for research investment decisions.

A comprehensive review of the evidence is needed, both to minimize the risk of the selection bias inherent in partial, qualitative summaries and to allow a comparative assessment of the relative returns among alternatives within agricultural R&D. In addition, a comprehensive analysis of the literature can provide a basis for understanding *why* rates of return differ among studies, over time, among research fields, and so on. This comprehensive analysis should be based on a methodology that seeks to ensure unbiased, clearly understood evidence. The appropriate methodology is meta-analysis.

Definition and History of Meta-Analysis

Meta-analysis is, essentially, an analysis of analyses. The idea is to amass research findings statistically and elicit from them the "weight of the evidence" of the past studies. The array of statistical procedures used to analyze any type of data can be applied in a meta-analysis, although usually some modifications are required for statistical inference with a meta-data set. Meta-analysts ask two types of questions:

- Do past studies on the subject tend to show a significant effect of factor X on outcome Y?
- What is the magnitude of the effect of factor X on outcome Y, based on the evidence from past studies?

Statistical research synthesis, or meta-analysis, is a relatively young methodology. Prior to its inception, an accumulation of what was known about a particular research area depended upon narrative reviews and tabular compilations of a selection of the studies on the subject. The selection was usually made by a researcher writing a new article in the area or an expert asked to provide a review for a journal or book; few attempts were made to be exhaustive. This practice is still the norm in many disciplines.

Thinking about research reviews began to change in the early 1970s. Taveggia (1974) argued that research results are probabilistic, that when results appear to be contradictory they may be simply individual observations of a *distribution* of findings, and that this is often overlooked in research reviews. Feldman (1971:86) observed that "systematically reviewing and integrating . . . the literature of a field may be considered a type of research in its own right—one using a characteristic set of research techniques and methods." Light and Pillemer (1984:3–4) offered further criticisms of traditional research reviews (narratives):

> 1) The traditional review is subjective. One chooses which studies to include in a traditional review. There can be disagreement about that and that can lead to criticism of the conclusions drawn from the review.
> 2) The traditional review is scientifically unsound. "Vote counts" of significant or positive or negative effects can lead to serious errors. It ignores sample size, effect size and research design.
> 3) The traditional review is an inefficient way to extract useful information. This is especially true if there is a large number of studies.

They went on to conclude that "It is by capitalizing on study-level variation that reviews show their strongest advantage over even the most carefully executed single study" (45).

Mann (1996) cites an example in which Iain Chalmers, now a well-known meta-analyst, performed a retroactive meta-analysis of the studies of the effects of DES (diethylstilbestrol, a synthetic estrogen given to prevent miscarriages) and vaginal cancer in offspring. Using only studies available by 1955 he found evidence that would have strongly pointed to the dangers of DES, if someone had thought to synthesize the results and carry out a meta-analysis at the time. The practice was not stopped until the 1970s, and in the meantime many young women died or had vaginectomies.

The volume by Hedges and Olkin (1985), *Statistical Methods for Meta-Analysis,* helped elevate the quantitative synthesis of research to an independent subfield within the statistical sciences. Especially in medicine, where any one clinical trial usually has too few observations to achieve statistical validity, meta-analyses have become de rigueur since the late 1980s. One example is the 1994 meta-analysis of 300 published studies of aspirin, involving some 140,000 patients, which clarified the role of aspirin in reducing the incidence of heart disease (*The Economist,* August 9, 1997, p. 70). The Agency for Health Care Policy and Research of the U.S. Department of Health and Human Services launched the Evidence-Based Practice Initiative in late 1996. At that time, the agency disbanded its guideline development panels (of experts) in favor of evidence reports based on "*comprehensive* reviews and *rigorous* analyses of the relevant scientific evidence" from which to formulate medical practice guidelines (U.S. Department of Health and Human Services 1997, italics in original). The first of these reports was issued in January 1997 and dealt with the evidence from research into colorectal cancer screening. Some meta-analysts are proposing a central repository for all medical experiments. As each experiment is completed, it will be added to an automated meta-analysis of similar experiments. Then a committee will decide, as the body of data approaches "significance" in a particular area of inquiry, whether further study is warranted or if the inquiry can be put to rest. A similar repository exists as the Oxford Database for Perinatal Trials in the field of obstetrics (Mann 1996).

Today meta-analyses are conducted in areas as diverse as the effect of various treatment approaches on juvenile delinquency (Lipsey 1992) and the effects of grazing on vegetative species composition (Milchunas and Lauenroth 1993). A meta-analysis can be helpful for policymakers, who may be confronted by mountains of conflicting studies. Some believe this is an advantage of the approach (saving policymakers valuable time and avoiding policy mistakes), whereas others consider it a drawback (taking the view that policymakers have too much time on their hands as it is) (Mann 1996). Still meta-analysis is not yet a settled body of theory and statistical methods. Nonetheless, in more recent years the arguments seem to have shifted their focus toward *how* to do it properly and away from *whether* it should be done. "There is no reason that a study of studies shouldn't be conducted with the same scientific and statistical methods as an individual study. . . . Many think that it is essential that every study be found. More important is that the methods of finding studies avoid special biases" (Cook et al. 1992:6, 290).

The Basics of How a Meta-Analysis Is Conducted

A meta-analyst gathers together all the studies relevant to the issue to be addressed and then constructs at least one indicator of the relationship under investigation. For example, if the effect of exercise on the risk of breast cancer is the issue at hand, the analyst would record from each study the number of nonexercising women who contracted breast cancer out of the total nonexercising women in the sample, and the number who contracted cancer out of the total who exercised. This information could be combined into one indicator by subtracting the proportion who exercised and got cancer from the proportion who did not exercise and got cancer. This indicator would be constructed for each relevant study (after an extensive search of published and unpublished sources of studies had been made). These study-level indicators would then be used in much the same way as individual observations from a single experiment, to construct the meta-data set.

The unit of observation is at the level of individual studies, although there can be more than one observation per study, for example, if the study reports multiple experiments or results using several experimental methods. The set of observations becomes the meta–data set, which can be subjected to any quantitative methods the analyst considers appropriate. In some meta-analyses, only the overall mean and standard deviation of the study indicator are calculated, especially if there is only one type of treatment and one outcome per study, as in our breast cancer example. This is usually possible only with controlled experiments in the physical or biological sciences or in medicine. In the social sciences we are rarely fortunate enough to be able to control our studies to the point that only one factor (or even just a few factors) influences the results. Consequently our meta-analysis calls for a more complex statistical analysis, since we wish to consider multiple factors jointly as potential influences on the rate of return measure. For our purposes a study indicator would be a measure of the rate of return to research and the set of values of the explanatory variables associated with that measure.

In the economic disciplines, meta-analysis has been used consistently only in the area of market research to analyze consumer response to various external stimuli such as advertising (Farley and Lehmann 1986). In agricultural and resource economics, meta-analyses have been limited so far to syntheses of studies measuring the value of a natural resource (Smith and Kaoru 1990; Smith and Osborne 1993; Boyle et al. 1994; Smith and Huang 1995) and the effect of farm size on measures of crop yield risk (Marra and Schurle 1994). All these studies used multiple regression techniques to meta-analyze the effect of several factors on the study outcomes. The same approach is employed here.

Objectives and Scope

The general objective of this study is to determine what the evidence says about the rate of return to agricultural R&D, to present that evidence in a summary fashion, to identify how and why the estimated rate of return differs among studies, and to interpret these findings so that they can be used by those who must decide how much money to make available for agricultural R&D and how to allocate it. A more ambitious study might include all industrial R&D and formally evaluate the relative rate of return between agricultural and nonagricultural R&D.

One objective is simply to summarize the distribution of estimated rates of return, both overall and for particular subgroups of studies (for example, by field or for particular time periods). But a more meaningful understanding of the relationship between particular study characteristics and the results can be found by considering the characteristics *jointly,* in a multivariate analysis. It is important to have realistic expectations about what conclusions can be drawn from a study of this kind. Although we document the patterns in rates of return among studies and attempt to isolate the relationship between particular characteristics of studies and the resulting estimates of rates of return in a multivariate analysis, these are only statistical associations. It is a significant step to go beyond association and infer causation. But this is a caution that applies to all narrative reviews—and indeed to most statistical inference.

CHAPTER 3

Measures of Research Impacts

We now consider alternative measures of research impact, focusing for the most part on economic measures, including the internal rate of return (IRR). We justify the use of economic measures and summarize the theory underlying the measures, identifying some pitfalls and problems along the way. Our main purpose is to document what the rate of return to research, as typically calculated, means and the implications of methods of calculation for interpretation of the measures themselves.

Multiple Measures

A variety of measures have been proposed and used to evaluate the impacts of agricultural R&D, sometimes as a basis for setting research priorities. For instance, Alston, Norton, and Pardey (1995) document economic measures, while several publications (for example, Horton et al. 1993 and the references therein) elaborate on other, sometimes qualitative and often noneconomic, alternatives. Research has impacts on a variety of dimensions, from scientific, biophysical, and agronomic effects (such as yields) in the experimental setting to a range of effects on people and the planet when the results are adopted commercially. Different measures of impact may be appropriate for different purposes. Nonetheless it is important to recognize that some of these measures may simply represent different perspectives on the same fundamental effects, that in some cases individual measures may have been combined into more comprehensive summary measures, and that some measures may actually misrepresent the effects they are claimed to represent. That is, the differences among measures may be meaningful, albeit perhaps misunderstood, or merely mistakes.

If the purpose at hand is to evaluate a biological or physical impact, for whatever reason, then a corresponding biological or physical criterion (and measure of performance against it) is appropriate. If, however, the purpose of research is perceived as social or economic, then socioeconomic measures are required. Problems arise because not everyone perceives the same purpose. Many, for instance, say the purpose of agricultural R&D aid is to raise the living standards of the poor, and if that is the right purpose then the performance measure perhaps ought to relate to poverty. Some, however, say that an appropriate criterion, even in poor countries, is total economic growth, taking the view that other policy instruments can be used to deal with income distribution problems or that the most effective way to tackle the poverty problem with R&D is by pursuing a growth strategy. Even if it is agreed that economic growth is the objective and the yardstick, different measures may be proposed for measuring performance against that yardstick. For instance, some propose simply using changes in yields as a proxy for contributions to economic growth (although how to do that is not at all clear, since they are not comparable measures), whereas others may use research-induced changes in net national income, recognizing that yields are driven by factors other than R&D and that it is net benefits, not gross benefits, that count. Somewhat more difficult questions arise when multiple purposes are perceived, such as raising economic growth and preserving the environment. Defining an appropriate yardstick for such settings is problematic, and a consideration of these issues led Alston, Norton, and Pardey (1995) to propose the use of a broad measure of net social benefits rather than scoring across multiple objectives.

The economic basis for government involvement in agricultural R&D is a perception of market failure leading to private underinvestment in R&D (for example, Nelson 1959; Arrow 1962; Alston and Pardey 1998). An appropriate criterion for the assessment of policy aiming to correct market failure is the effect on net social benefits, and this can be expressed as a social rate of return to public investment in agricultural R&D. This line of reasoning justifies the use of measures of social rates of return as evidence of the extent of market failure in agricultural R&D, as evidence of the success of past public policies for mitigating private underinvestment in R&D, and as information for guiding the allocation of research resources. This is the primary, and a sufficient, justification for using the economic measures—net social benefits. But there is another reason. The alternative measures are partial. How do we combine and thus compare information about the effects on the environment, employment, and consumers of, say, a new high-yielding variety versus an infrastructure project? We need some basis for weighting the different elements of the set of impacts. The economic approach is based on the idea that prices are useful (indeed, ideal) measures of the relative values of different things, and when we weight all the various impacts using appropriate prices the resulting measure corresponds to net social benefits.

Dynamics of Research Benefits and Costs

Successful investment in agricultural research leads, among other things, to increases in agricultural productivity, so that either more output can be produced with the same amount of total inputs or the same amount of output can be produced with a smaller quantity of inputs. Economists dub this *productivity growth.* These increases in productivity stem from the development of new or improved outputs; from new, better, or cheaper inputs; or through other changes in the stock of useful knowledge that enable producers to choose and combine inputs more effectively.

The two principal methods that have been used to evaluate the benefits from research are (1) estimating changes in consumer and producer benefits using a supply and demand model of a commodity market, and (2) using regression analysis to estimate an aggregate production (or productivity, cost, or profit) function model that can be used to evaluate the additional output (for given inputs) or the saving in inputs (for given output) attributable to past investments in R&D. All such evaluations of the economic effects of research involve relationships between the size of investment in research and output or productivity, relationships between increased productivity flows and economic benefits, and procedures to account for the timing of the streams of benefits and costs, since there may be lengthy (perhaps infinitely long) lag times between the initial investment in research, the eventual adoption of research results, and the *full* realization of benefits.

The lags between investing in R&D and reaping some return on that investment can be quite long, since some inventions are slow to come forth and, whereas some are comparatively short lived, others last a long time or are used in subsequent R&D, leading to further cycles of invention and streams of benefits. These lags are a crucial factor in determining the benefits from R&D and may be an important reason why there is underinvestment. In addition, analysts attempting to measure those benefits can over- or understate the true benefits by large amounts if they make errors in estimates of, or assumptions about, the lag structure (for example, Alston and Pardey 1996, Chapter 6, provide arguments and numerical illustrations; Alston, Craig, and Pardey 1998 provide an empirical case study).

Figure 1 represents schematically the timing of flows of benefits and costs from investing in a successful agricultural R&D project that results in a particular innovation. The vertical axis represents the flow of benefits and costs in a particular year and the horizontal axis represents years after the commencement of the R&D project. Initially the project involves expenditure without benefits so that, during the "gestation" or research lag period (say, three to five years but often longer, depending on the nature of the research), the flows of net benefits are all negative.[6]

Suppose the research is successful, leading to a commercially applicable result.[7] Then after the research lag there may be further delays, including a "development lag" of several years and an "adoption lag" that may also last several years. A conventional justification for extension has been that it shortens the adoption lag so that benefits are achieved earlier.[8] Eventually, as shown in the figure, the annual flow of net benefits from the adoption of the new technology becomes positive. In some cases the flow of benefits may continue indefinitely, but in many cases the flow of benefits will eventually decline.

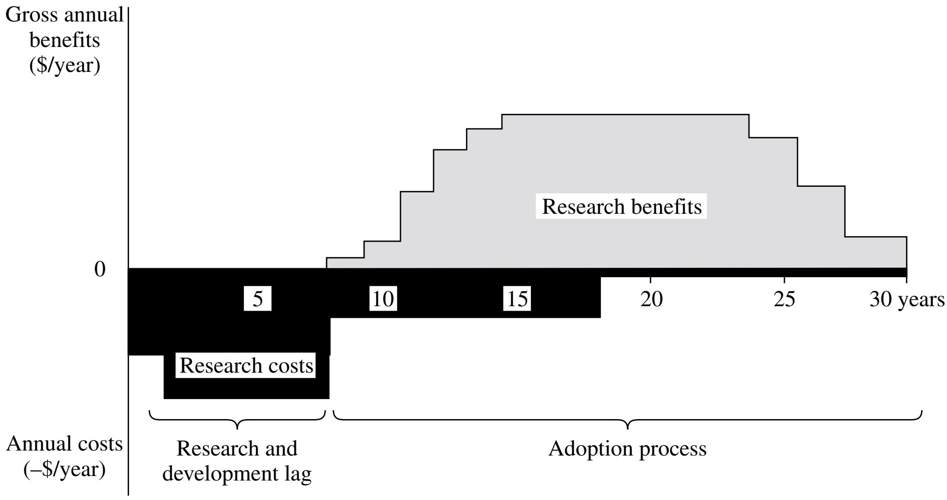
---

[6] For more basic or pretechnology research, the lags before adoption would typically be much longer and the range of relevant innovations could be large, each having a different individual benefit lag profile.

[7] The majority of research projects do not lead to a commercially viable result; however, the successful projects (perhaps as few as 1 in 20, even in applied agricultural R&D settings) generate enough benefits to cover their own costs and the costs of the unsuccessful ones (assuming a rate of return greater than zero).

[8] Earlier benefits are worth more because the proceeds can be reinvested. Empirical work has shown that there is a very high payoff to shortening the typical lags, even by just one year. These considerations provide a justification for extension efforts directed toward speeding up the process of innovation.

Figure 1—Flows of resources, benefits, and costs



Source: Alston, Norton, and Pardey 1995.

Figure 1 shows the flows over time of net annual benefits attributable to the R&D project. They represent the sum of benefits across individuals in the society, accruing in each year, relative to the situation if the project had not been undertaken. We need to make a comparison with and without the R&D, not simply before and after it. Why is this so? It might be that for a particular commodity yields have not risen, yet yield-enhancing research has been successful and highly beneficial.[9] In many cases the relevant alternative would not be constant yields but falling yields (or rising costs to maintain past yield performances as, say, increased pesticide, crop management, and labor costs are incurred to counter the effects of pests evolving and becoming resistant to earlier crop variety releases or pesticides).[10] Indeed "maintenance research," research directed at maintaining yields and profitability in the face of pressures that would otherwise lead them to fall, is a major component of agricultural R&D.

---

[9] The definition of the counterfactual scenario—what would happen in the absence of local research—is made even more complicated by the important role of spillins of technology from other states or countries, which mean that in some places, even absent local research (except, perhaps, some adaptive roles) productivity would still grow. In a similar vein, some public research may be crowding out private research so that changes in public research *cause* changes in what would otherwise happen.

[10] Significant research investments—particularly in plant breeding, plant pathology, and entomology—are required just to maintain productivity at previous levels. Estimates indicate that 35–70 percent of U.S. agricultural research is needed to maintain previous research gains (Heim and Blakeslee 1986; Adusei and Norton 1990).

Types of Evaluation Questions and Attribution Issues

Figure 1 relates to the dynamics of payoffs to a *particular* project. Often such projects are perceived as involving costs in an early year (or a few years) to be followed by a stream of benefits beginning somewhat later and extending for many years. The counterfactual experiment in the evaluation of that type of investment involves asking what would happen if the investment did not happen at all, or if it were changed marginally. But many agricultural R&D evaluation problems involve a different type of question. They relate to, for example, a research program or portfolio of projects and programs within an institution or across all the institutions that make up a country's national agricultural research system. In this type of problem, we are comparing hypothetical changes in a continuous stream of investments and the implied hypothetical changes in the corresponding stream of benefits. In both types of analysis it is necessary (indeed very important) to ensure that the stream of benefits matches the stream of costs. In the first type of problem, we are considering one element in a portfolio, and it might have a well-defined and well-measured profile of research lags (for example, we know how long it took to develop, release, and adopt a particular variety of wheat). In the second type of analysis we are trying to develop information on the average lag profile across the entire inventory of projects and programs within the portfolio being assessed (for example, all research undertaken at the International Center for Improvement of Maize and Wheat [CIMMYT]).

Even so, the difference is defined by the analyst's choice of which counterfactual scenario to simulate. One could simulate a one-shot, one-year change in the program developing a particular wheat variety, in the overall wheat-breeding program, or in the entire portfolio of work in basic biological research, crop improvement, and so on. The essential distinction is that it is easier to know the lag structure for some types of research than for others.

In every one of these experiments, it would be appropriate to be concerned about the attribution question: how much of the measured change in benefits is truly attributable to the simulated change in R&D costs, and how much ought to be attributed to some other factor? When simulating an entire portfolio the odds of inappropriate attribution among different parts of the agricultural research portfolio are reduced, but the extent of the remaining problem will depend on how much of the action is being driven by other investments not reflected in the analysis. For instance, how much of the gains within agricultural science are truly owed to nonagricultural scientists within the more general biological or physical sciences?[11] Or, how much of the gains attributed to U.S. wheat breeders in some studies are really attributable to breeders in the international centers, and perhaps vice versa?[12]

---

[11] Some evidence of the cross-disciplinary linkages within the biological sciences is provided in Huffman and Evenson's (1993:54–58) Table 2.6 and the related discussion.

[12] Pardey et al. (1996) provide evidence on the size of these spillovers and discuss the attribution problem.

Supply and Demand Models of Research Benefits

A conventional commodity market model of the economic impacts of agricultural research shows how the benefits can be assessed and identifies the important elements of such an assessment. All rate of return estimates rest on a variant of this model (although sometimes only implicitly).[13] First we present a basic model of a closed economy (an economy with no international trade). The basic model has been widely used in evaluation of R&D, but it rests on some simplifying assumptions that are not appropriate for every analysis. We also discuss extensions that have been made to the basic model to accommodate international and interstate trade in commodities, to incorporate technological spillovers, to allow for different types of technological change, and to adjust for market distortions arising from government interventions in commodity markets, the market power of firms, and environmental externalities (for example, see Alston, Norton, and Pardey 1995).

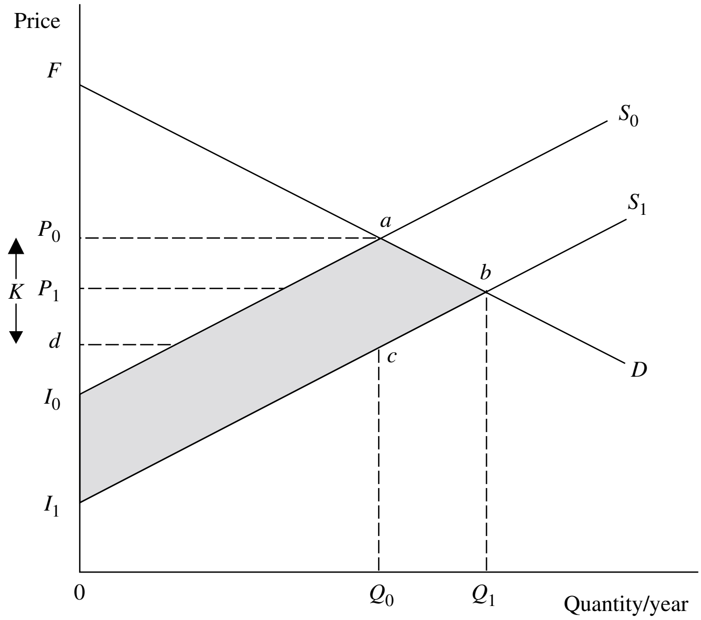
Basic Closed Economy Model

The basic commodity market model of research benefits is represented in Figure 2: S_0 represents the supply function before a research-induced technical change and D_0 represents the demand function. Initially the price and quantity are given by the intersection of supply and demand at P_0 and Q_0. Suppose research leads to a saving of K per unit in average and marginal costs, reflected as a parallel shift down in the supply function to S_1. This research-induced supply shift leads to an increase in production and consumption to Q_1 (by $\Delta Q = Q_1 - Q_0$) and price falls to P_1 (by $\Delta P = P_0 - P_1$). Consumers are better off because the R&D enables them to consume more of the commodity at a lower price. Consumers benefit from the lower price by an amount equal to their cost saving on the original quantity ($Q_0 \times P$) plus their net benefits from the increment to consumption. Although they receive a lower price per unit, producers are better off, too, because their unit costs have fallen by an amount (by K per unit) that exceeds the fall in price. Producer profits per unit are greater by the increase in profit on the original quantity—$Q_0 \times (K - \Delta P)$—plus any profits earned on the additional output. Total national benefits are obtained as the sum of producer and consumer benefits.

As an intuitively reasonable approximation, many would use the cost saving per unit multiplied by the initial quantity to approximate gross annual research benefits (GARB) (GARB = $K \times Q_0$), and this approximation is theoretically defensible (for example, see Martin and Alston 1997). Often this will be represented, equivalently, by defining a proportional cost saving on the original quantity ($k = K/P_0$) so that GARB = kP_0Q_0. In other words, a k percent reduction in unit costs yields a benefit equal to k percent of the value of production.

[13] However, a number of important elements of agricultural R&D are not embodied in agricultural inputs or outputs, and their full impacts might not be reflected in agricultural commodity markets.

Figure 2—A supply and demand model of research benefits



Source: Alston and Pardey 1996.

Open Economy Model

The foregoing model pertains to a closed economy in which all the impacts are experienced within the economy. This is not an appropriate representation for a traded good, in cases in which domestic production (or consumption) of the commodity is not consumed (or produced) entirely domestically. Further complications are added when overseas producers can also adopt, and benefit from, the technology developed domestically. For many studies, it is necessary to allow explicitly for interregional or international trade in the commodity, and to allow for technological spillovers when others adopt the results from R&D. An important disadvantage of this approach is that, although it is relatively easy to approximate global benefits, using the total measure defined previously as the cost saving per unit times the number of units ($K \times Q_0$) to disaggregate into domestic and foreign components requires significantly more information (including details on the price responsiveness of supply and demand and the fractions traded). On the other hand, in many cases there is an offsetting gain in simplicity because, in a global context, many countries or regions can be treated as a *price taker* (when their production is not large enough to affect world or national prices appreciably) for many commodities, so that it remains feasible to approximate both domestic and global benefits as ($K \times Q_0$). Nevertheless the counterfactual matters, since technology adopted elsewhere can lower the price for a price taker.

Effects of Distortions

The measures of benefits discussed in the previous section are based on an assumption that marginal *private* costs and benefits from consumption are equal to marginal *social* costs and benefits. Three types of market distortions that may have implications for measuring benefits from R&D are (1) those due to government intervention in commodity markets, (2) discrepancies between private and social benefits and costs of production when there are environmental externalities (for example, air or water pollution) associated with production, or (3) where agribusiness firms have market power in commodity markets. Studies by agricultural economists have shown that the most important effect of the presence of market distortions is to change the distribution of benefits, with ambiguous impacts on net benefits.[14] Thus the assumption of undistorted markets may not matter too much for the aggregate measures—at least for nontraded goods or goods traded by a small country, for which national benefits do not depend on the international distribution of benefits.

Supply Shifts

Some other assumptions in the foregoing analysis are important, and their effects are unambiguous. As discussed by Alston, Norton, and Pardey (1995) among many others, the measures of GARB depend on assumptions about the functional forms of supply and demand, the elasticities of supply and demand, and the nature of the research-induced supply shift. The latter, in particular, matters and is always assumed rather than established empirically.[15] The most common alternative to the assumption that supply is linear and that it shifts in parallel is that it is linear in logarithms and shifts proportionally, although proportional (or pivotal) shifts are also used with linear functions. The measure of GARB with a proportional shift is roughly half the measure from a parallel shift in supply by the same amount at the original quantity, when all other elements of the analysis are the same.

---

[14] For example, Alston, Edwards, and Freebairn (1988) and Martin and Alston (1994) deal with government policy effects; Alston, Anderson, and Pardey (1995) discuss environmental externalities; Sexton and Huang (1996) and Alston, Sexton, and Zhang (1997, 1999) develop models with market power. Moschini and Lapan (1997) analyze a case in which firms have market power over the pricing of inventions, arising from intellectual property protection; this is a different type of market power with entirely different implications. See also Venner (1997) and Alston and Venner (2000).

[15] The importance of the nature of the supply shift induced by research, and how to know the nature of the shift, has occupied much of the literature on the returns to research. The issue was crystallized by Lindner and Jarrett (1978) and the ideas were summarized by Norton and Davis (1981). A more recent discussion and review is contained in Alston, Norton, and Pardey (1995:63–65). Wohlgenant (1997) adds the confounding effects of entry and exit of firms to the long-standing arguments that indicate it is hard to know from firm-specific information what is implied for industry supply shifts.

Benefits That Do Not Show Up in Commodity Markets

The approaches discussed previously are useful for relatively applied types of research that lead to results embodied in inputs or outputs, the effects of which are reflected in commodity markets. We can measure the impacts in commodity markets after new technology has been adopted, or we can use commodity market models to infer the implications of such types of technical change based on experimental information. Unfortunately this type of analysis is much less useful for more basic research, especially ex ante (since, by definition, we cannot anticipate the application of the results of truly basic research). And it is less applicable to the analysis of the impacts of work in certain fields, such as social science research, in which the results are not easily modeled in terms of their effects on commodity markets (see Christian and Pardey 1999). The same may be true of environmental research or research into natural resource management.

It should be remembered that the commodity market model has always been an indirect way of determining the benefits from research. A direct analysis of the economics of hybrid corn research would use a model of, for example, the market for hybrid corn seed or for scientists working on it (that is, the output from, or input to, the activity of direct interest). The commodity market for corn is one step removed, but it has the virtue of having clearly and readily observable prices and quantities and therefore can provide a good measure of the impacts of hybrid corn research (although the effects of other research are more likely to be present, and potentially misattributed, the higher the degree of aggregation). The same closeness of approximation does not follow nearly as well for many other types of research, and different modeling approaches may be called for. Perhaps unfortunately, all the studies of returns to agricultural R&D have adopted the commodity market model, either implicitly or explicitly, which means that only certain types of research have been modeled. This has particular implications for the literature on evaluation of natural resource management research. The meta-analysis may not be able to give us clear evidence on how the commodity market orientation of the literature has affected the measured returns.

Aggregation over Time: Summary Statistics

Different extents of adoption of new technology imply different sizes of shifts in the industry supply function. The total benefit (area I_0abI_1 in Figure 2) corresponds to the flow of benefits in a particular year (that is, the height of the curve at a particular point in Figure 1) for which the supply shift depicted in Figure 2 represents an appropriate measure of the impact of the R&D at the corresponding stage of adoption. Thus a model such as that in Figure 2 can be used to construct the curve represented in Figure 1 by varying the size of the supply shift to reflect the changing pattern of adoption over time.

In order to compare projects that have different time patterns of costs and benefits, we must aggregate over time. Capital budgeting techniques are appropriate, and the relevant techniques are well known and documented.[16] If a dollar were worth the same to the recipient, regardless of when it is received, we could simply add up annual flows of net benefits over time. Capital budgeting addresses explicitly the idea that a dollar today is worth more than a dollar tomorrow, or in 10 years' time. Evidence of people's time preference for money is clear from the need to pay interest when we borrow money. Correspondingly a dollar received today can be invested and will accrue interest and *will* be worth more in 10 years' time than a dollar received in 10 years' time. In capital budgeting, we discount future benefits and compound past benefits relative to current benefits. That is, we express all past and future flows of benefits and costs in *present value* terms.

Net Present Value

The present value, in year t, of a stream of research benefits (B_{t+j}, the benefit in year $t + j$) over the next n years can be expressed as

$$\mathrm{PV}(B)_t = B_t + B_{t+1}/(1 + i) + B_{t+2}/(1 + i)^2 + \ldots + B_{t+n}/(1 + i)^n,$$

where i is the interest rate used to discount future benefits. More compactly we can write

$$\mathrm{PV}(B)_t = \textstyle\sum_{j=0}^{\infty} B_{t+j}/(1 + i)^j.$$

Comparing the stream of benefits (B) and costs (C) of a project, the *net present value* is equal to

$$\mathrm{NPV}_t = \mathrm{PV}(B)_t - \mathrm{PV}(C)_t = \textstyle\sum_{j=0}^{\infty} (B_{t+j} - C_{t+j})/(1 + i)^j.$$

That is, the net present value is equal to the present value of the stream of net benefits. In many instances we are comparing a stream of benefits to a one-time cost in year 0, but this is just a special case of the more general one. An investment is profitable if the net present value is positive (in other words, if the present value of the benefits exceeds the present value of the costs).

Several conceptual and measurement issues are implicit in this formula and should be made explicit. First, whether we are interested in *social* benefits and costs (the sum of those accruing to any member of the society), as opposed to *private* benefits and costs (the sum of those accruing only to a particular group in the society), does not affect the formula. It does determine how we measure the relevant streams

[16] For instance see Robison and Barry (1996) for a comprehensive treatment or Alston, Norton, and Pardey (1995:362–364) for a discussion of applications to agricultural research evaluation and priority setting.

of benefits and costs. It is important to be clear about what is intended to be measured in deciding what to include and how to interpret the resulting estimates.

Second, the discount rate *i* should be defined and measured in a way that is consistent with the measures of benefits and costs. In particular, if the streams of benefits and costs are defined in *nominal* terms, which means that they are in dollar values that are observable in the marketplace and not adjusted to remove the effects of inflation, then a *nominal* discount rate is appropriate. To represent the nominal risk-free real rate of return it is common to use the interest rate on long-term government bonds, for instance. On the other hand, when benefits are being projected forward it is common to project them forward in current value terms (that is, without adjusting for future inflation effects), and these benefits are effectively in *real* terms, calling for a *real* (inflation-adjusted) discount rate. If it is desired to use a real discount rate but the streams of costs and benefits are in nominal terms, the value streams can be converted to real terms by dividing by a general price index such as the Consumer Price Index. Some studies have failed to appreciate these distinctions and have used rather large discount rates (say, 10–15 percent) to discount real streams of benefits and costs. Real risk-free rates of interest are typically in the range of 2–5 percent.[17]

Third, several issues arise in the interpretation of the net present value. It can be an *average* net present value, in the sense that it reflects all the costs and all the benefits from a particular project or program of work, compared with what would happen if *no* such investment were made. Or it can be a *marginal* net present value, reflecting the benefits from a comparatively small change in the total investment. Both marginal and average measures of profitability may be of interest, but for different questions: for example, should the research be shut down versus should it be reduced? Marginal and average net present values are not really comparable, since they refer to different scales of investment, but marginal and average rates of return or benefit-cost ratios are adjusted for the scale of the project, seem comparable, and could be confused for one another. It is accordingly useful to know what is being measured in settings in which the marginal and average measures may differ.[18]

[17] Another issue concerns risk itself. Should the discount rate include a premium to account for the fact that investing in research is a risky business? Alston, Norton, and Pardey (1995) reviewed the arguments and concluded that public R&D investments should be evaluated using risk-free discount rates (although the issue of whether R&D leads to changes in farmers' risks remains relevant). On the other hand, the same conclusions may not pertain to private rates of return.

[18] Unless the relationship between research investments and benefits is linear, the per-unit benefit will vary with the size of the total investment. The marginal benefit measures the additional benefit from the last unit of investment, whereas the average benefit divides the total benefit by the total investment. Timing also matters. *Marginal* could refer to changing within one year or many years, and *average* could be for one year or all years. Applying these concepts is slippery, and studies do not always make the interpretation entirely clear. With nonlinear relationships, the average and marginal benefits need not even both take the same sign: the marginal benefit could be negative even though the total investment is still profitable.

Benefit-Cost Ratio

Whereas the net present value (NPV) is usually regarded as the best measure for most purposes, two other measures are used more commonly, largely because they are more readily comparable across investments. A benefit-cost ratio is given by the ratio of the present value of benefits to the present value of costs, rather than the difference between them. That is,

$$\mathrm{BC}_t = \mathrm{PV}(B)_t \div \mathrm{PV}(C)_t.$$

An investment is profitable, according to this criterion, if the benefit-cost ratio is greater than 1 (that is, again, if the present value of benefits exceeds the present value of costs).

Internal Rate of Return

A third, alternative way of representing the same information is the internal rate of return, IRR. This is defined as the discount rate that yields NPV = 0. That is,

$$0 = \textstyle\sum_{j=0}^{\infty} (B_{t+j} - C_{t+j})/(1 + \mathrm{IRR})^j.$$

An investment that has NPV > 0, given a discount rate of i, will also have an IRR > 0. Thus, according to the IRR criterion, an investment is profitable if the computed IRR is greater than the required (market) rate of return: IRR > i. As described here, the three criteria (NPV > 0; BC > 1; IRR > i) are equivalent, and in many instances they will be so. But in some instances they are not equivalent (for instance, when the stream of *net* benefits changes sign, or when the stream of net benefits cannot be assumed to be reinvested at the same rate of return). Although the theoretical arguments favor the NPV criterion, most empirical studies of returns to research have computed IRRs instead, perhaps because the rates of return are perceived to be more meaningful to noneconomists. Accordingly, in this study, we will use the IRR as our yardstick.

As with the other related summary statistics, rates of return can be nominal or real, social or private, and marginal or average. The distinctions matter and are not always clearly made in (or possible to infer from) published studies that report rates of return.

Translating Benefit-Cost Ratios to Rates of Return

In order to expand the available data set, we can infer an approximate IRR from studies that publish only a benefit-cost ratio (if they publish more information, we might be able to make a better approximation). To do this we assume the benefit stream can be approximated by a perpetual annual flow of benefits, B per year, while the costs can be approximated by a one-time expenditure, C in year t. Thus

$$\mathrm{PV}(B)_t = \sum_{j=0}^{\infty} B_{t+j} /(1 + i)^j \approx \sum_{j=0}^{\infty} B/(1 + i)^j = B/i.$$

By the same token

$$\mathrm{PV}(C)_t \approx C_t = \mathrm{PV}(B)_t \text{ (at IRR)} \approx B/\mathrm{IRR}.$$

Thus

$$\mathrm{BC}_t = \mathrm{PV}(B)_t \div \mathrm{PV}(C)_t \approx (B/i) \div (B/\mathrm{IRR}) = \mathrm{IRR}/i.$$

Hence we can approximate the IRR by multiplying the benefit-cost ratio by the required rate of return: IRR ≈ (BC)i.[19]

This approximation involves an assumption of a perpetuity and the use of a particular discount rate, i. Both may lead to biases. If the stream of net benefits had been used to compute an IRR, presumably it would involve larger flows in some years and smaller ones in others, rather than equal annual flows as from a perpetuity. In particular, the typical analysis of research benefits involves no benefits or small benefits during the early years and none after a terminal period when benefits cease. Second, some studies do not report the discount rate used to compute the benefit-cost ratio. In the absence of a reported rate, rather than assume a rate, we dropped the observation (this involved only three observations). Although the bias could go either way, our initial guess was that the perpetuity approximation would lead to an overstatement of the rate of return.

[19] Griliches (1958, 1980) made a similar point, and his benefit-cost ratio of 7:1 is consistent with a rate of return of 35 percent per year.

CHAPTER 4

Measurement Issues and Problems

Some economists suspect that the estimated rates of return to R&D in the literature may have been systematically biased upward because the procedures used tend to understate the costs and, perhaps, to overstate the benefits. Understatement of costs arises, in particular, from not allowing for the full social cost of using general taxation revenues for R&D, because general taxation involves a social cost of more than one dollar per dollar raised (see Fox 1985). In addition studies occasionally fail to attribute an appropriate portion of R&D overhead (including the costs of associated basic R&D) to the particular projects being evaluated, or they omit components of effort involved in the development and extension phases of a project. Overstatement of benefits arises, in particular, from not counting the effects of private sector R&D and not counting the effects of spillovers of technology from other places (states, countries, or institutions) and attributing all the gains in productivity to only a subcomponent of the total relevant R&D spending.

As the foregoing simple models show, and as Alston, Norton, and Pardey (1995) discuss in great detail, the critical determinants of the rate of return to a particular research program can be distilled into (1) k, the percentage research-induced reduction in costs of production when the results are adopted, (2) P_0Q_0, the size of the industry affected, (3) the nature of the research-induced supply shift, and (4) the timing of the flows of benefits (the research lags). Errors are likely to be small in estimating the value of production in the industry, at least in more-developed countries, which have more reliable agricultural statistics.[20] However, in developing countries, where a large proportion of production is not marketed and poor infra-

[20] It is necessary to project the value of the industry forward in the "without research" scenario in order to evaluate the impacts in the future years when the research results are adopted. Although it may be reasonably straightforward to estimate P_0 in the current year for many cases, choosing the right stream of values for P_0 may not be so easy in some market situations, as when markets are distorted by government programs, in cases of infant industries for which markets are not well established, or in other situations in which it is difficult to project accurately far into the future. In relation to market distortions, Alston, Norton, and Pardey (1995) suggest that the issue is not so much one of choosing the right price but, rather, modeling the nature of the distortion properly, in ways that best reflect the overall welfare consequences of R&D.

structure may result in high transaction costs, arriving at the appropriate value for some commodities is no small feat. The analyst chooses the form of the research-induced supply shift; the remaining key dimensions in which choices by the analyst can affect the outcome are in the estimation of k and the research and adoption lags.

Apportioning Costs and Benefits and Double-Counting

Some problems relate to the measurement of the streams of benefits and costs such that the measures match up to the concepts they are meant to represent. Some of these issues are straightforward. For instance, many studies attribute all the growth in productivity in a particular industry in a particular place to local public sector expenditures on agricultural R&D specific to that commodity. This approach ignores the contribution of private sector R&D (including the cost of development work to allow the results from public sector R&D to be adopted), fails to count the costs of basic R&D that may underpin the commodity-specific applied work, does not count the costs of extension, and assumes that the gains resulted from the local commodity-specific research rather than from spillovers from the same industry in other places or from other industries.

A comprehensive evaluation would take into account all the relevant costs and all the relevant benefits. This, however, can be tricky. For instance, it is hard to know in many instances what is the source of a particular idea leading to an innovation. Apportioning overhead costs among projects or programs is not a straightforward process, especially when individual scientists are engaged in multiple activities (for example, research and teaching). Studies that evaluate entire institutions can avoid the problem of apportioning costs but run into different problems. For instance, in ex ante assessments different scientists may be working on different projects that are mutually exclusive (for example, different varieties of the same crop that cannot both be adopted in the same place), and the total benefits are not simply the sum of the benefits of all the projects (actually this is a problem with the evaluation of the individual projects that is only revealed when we consider them together). On the other hand, an institution-level evaluation will avoid the problem of selection bias, in which only the successful projects are evaluated (that is, counting all the benefits against only a fraction of the costs).

Another set of problems arises in institutions having multiple roles, such as land grant colleges, which are engaged in teaching, research, and extension, or the CGIAR, with its roles in technology creation, scientist training, germplasm preservation, and institution building. When measuring the returns to the R&D activities, we should attribute an appropriate part, but not all the total costs, and some of the costs (in particular the overhead costs) are hard to apportion appropriately. On the other hand, if we are assessing the entire set of the institution's investments, how do we measure the benefits from, say, institution-building programs? In principle the proper approach is clear. In practice the benefits and attributable costs are diffuse and difficult to measure—especially within the confines of a commodity market model.

Another potential source of overstatement of benefits is the typical failure to accommodate commodity programs or other distortions—although, as noted previously, the effects of such omissions are ambiguous. On the other hand, benefits may be underestimated by the omission of environmental and natural resource management benefits, even though we count the cost of research related to these areas. However, it is more likely that past R&D (particularly private R&D) has led to technologies that exacerbate, rather than ameliorate, the negative environmental consequences of agriculture, so the omission of these effects has given rise to generally overstated social rates of return (see the section "Benefits That Do Not Show Up in Commodity Markets" in Chapter 3 and Alston, Anderson, and Pardey 1995).

Selection Bias

It is likely that, within any large portfolio of research projects, there will be a wide range of rates of return, including some failures. A reasonable analogy may be drawn with oil exploration—the incidence of dry holes does not deter investment when experience of drilling in similar conditions suggests overall profitability.[21] In ex post evaluation, it is natural for some to focus on the successful projects or programs. This is a problem only if the rate of return to the winners is misinterpreted as representing the overall rate of return. The problem of selection bias can be perceived as the converse of the problem of apportioning costs and avoiding double-counting benefits, so that the streams of benefits and costs are appropriately matched. Nevertheless in a meta-analysis we would like to be able to make use of the fact that some studies may have deliberately selected "winners" for evaluation. Many of the studies are based on production function analyses of aggregate data, and these would include many research evaluation studies that evaluated not just selected projects but all the research over specified time periods in particular research institutions or particular industries. If selection bias matters, we may expect to find systematically lower rates of return for these more aggregative studies.

Measuring *k*

How k is measured matters. Often the first step is to measure a percentage increase in productivity attributable to research, and for such measurements a range of methods may be used (for example, by expert opinion, from experimental data, from industry-level productivity models). There may be some error in going from an estimate of productivity change that applies in one context to an industry-level supply shift. Typically experimental yield changes ($y = \Delta Y/Y$, holding input quantities con-

[21] In reality, of course, research is usually a highly uncertain venture, even when the desired end result is clear. There may also be unforeseen spin-offs, particularly from more basic types of scientific research, in which results may give rise to highly profitable applications that could not have been anticipated before the project started.

stant) are taken to be representative of the percentage rightward shift of supply j (= $\Delta Q/Q$, holding output price constant). In principle j measures the changes in quantity produced, allowing for optimal adjustments in input quantities by producers. In practice, however, y holds the input mix constant if experimental yields are being used. On the other hand, if industry yields are being used, it is necessary to isolate and adjust for those parts of y that are attributable to other factors (for example, changes in inputs, pests, or weather), in order to identify the part that is attributable to research-induced changes in technology. An additional source of error comes from the way j is typically converted to k. If j is converted to k using a value for the supply elasticity ε (for example, $k = j/\varepsilon$) the supply elasticity becomes a potential source of error. In some studies, very large values for k and rates of return can be attributed to the use of experimental yield data combined with a very small value for the supply elasticity.

Model Specification Choices

The problems that can arise in the estimation of k are sometimes related to other aspects of the model specification that have implications for the results. One choice, for instance, is whether to use an explicit economic surplus model or an implicit one (that is, GARB = kP_0Q_0). This implicit economic surplus model has some built-in implicit assumptions about the horizontal and vertical market structure (namely that the consuming and producing groups in different regions and in the food marketing chain, and the corresponding elements of welfare measures, can be collapsed meaningfully into a single market) and the absence of market distortions, which may represent important abstractions, leading to significant bias, in some applications. The implications of the abstractions involved in particular modeling choices depend on the situation. Sometimes the above approximation is quite reasonable; at other times it is not at all reasonable.

Lag Distributions

Choices about the specification of the lag distribution, relating research expenditure at a point in time to subsequent flows of research benefits (as discussed in the section "Dynamics of Research Benefits and Costs" in Chapter 3), might be especially important. In empirical work on models of effects of research on aggregate agricultural productivity, the number of lags and the shape of the lag structure are usually chosen arbitrarily; rarely is either the lag length or the lag form tested formally. Common types of lag structures include the de Leeuw or inverted V, polynomial, and trapezoidal. A small number of studies have used free-form lags, but most have restricted the lag distribution to being represented by a small number of parameters, because the time span of the data set is usually not much longer than the assumed maximum lag length.

Until quite recently it was common to restrict the lag length to less than 20 years. In the first studies, available time series were short and lag lengths were very short.

More recent studies have tended to use more and longer lags—but rarely lags of more than 30 years. In contrast Alston, Craig, and Pardey (1998) argued for using a finite lag between research investments and *changes in* the aggregate stock of knowledge to represent an infinite lag between aggregate research investments and productivity.

Alston, Craig, and Pardey laid out a model in which current production depends on the utilization of a stock of useful knowledge, which is itself a function of the entire history of investments in R&D—potentially an infinite lag between past investments in research and the effects on production. They noted that the stereotypical study of returns to agricultural research has used a comparatively short, finite, lag structure (typically with fewer than 30 years and often fewer than 15 years of past research investments used to explain current productivity). A short, finite lag may reasonably represent the link between investments in research and *increments* to the stock of useful knowledge, but it would be a significant conceptual error to use the same lag to represent the relation between investments in research and production, since production depends on flows from the entire stock of useful knowledge, not just the latest increment to it.

Alston, Craig, and Pardey held that the inappropriate truncation of the research lag is analogous to the classic "omitted variables" problem and would likely lead to an upward bias in a rate of return to research based on econometrically estimated lag weights. On the other hand, in an analysis in which the lag weights are not estimated econometrically, any truncation of the *assumed* lag distribution will simply reduce the overall size of the stream of gross and net benefits, and it must reduce the rate of return as a result.

Natural Resource Management Research

Environmental and other nonmarket impacts are difficult to capture in the conventional measures of benefits from agricultural research. Furthermore, benefits from research related to environmental or resource issues may be unusually difficult to assess, even when such research affects agricultural markets in ways similar to more traditional crop and livestock research. One result of research on resource or environmental topics may be to enhance agricultural productivity and reduce production costs relative to the outcome in the absence of the research. However, such productivity impacts are sometimes unknown and often subtle.[22] Productivity impacts are almost always difficult to measure because the processes of environmental degradation (or improvement) are difficult to quantify, even from a narrow agricultural productivity perspective, and the productivity impacts are gradual—although potentially profound. And measured productivity may not capture some of the important con-

[22] For example, Lindert (1996) found no evidence of a long-run decline in the fertility of agricultural soils, or in the total soil stock, throughout China and Indonesia. Although there has been some loss of land to urban growth, there has also been some refertilization of land at the urban fringe, making the full effects subtle and difficult to discern without careful empirical analysis.

sequences of research; for example, research into removal of selenium from the soil has complex multiple payoffs to agricultural productivity, but also benefits to wildlife (see Alston, Pardey, and Carter 1994).

Some benefits are partially measurable as shifts in the trend productivity growth rate. Often more important is the need to prevent productivity from falling, and this effect is not adequately represented in common estimates of rates of return. The relevant comparison is between the trends of productivity with and without such research, and these are difficult to assess. The problem is similar to assessing the payoff to "maintenance research" (discussed earlier), but much more difficult because environmental or regulatory factors have complex dynamic effects.

Conceptualizing Bias and Precision

It is useful to distinguish between two types of error: systematic error or bias that we can attribute to a decision in the analysis, and unavoidable, random error. To see this distinction more clearly, let us define the measured rate of return for a particular project or program p (m_p) as being equal to the true rate of return (m_p^*) plus a measurement error (v_p). That is,

$$m_p = m_p^* + v_p.$$

An ideal measure is one that has a very small error. (In this construction we may think of m_p as the signal about the true rate of return and v_p as the noise; we prefer a procedure that has a high signal-to-noise ratio.)

Different estimation approaches will imply different characteristics of the distribution of errors, which we can think of in terms of bias (the expected value of v_p is zero for an unbiased measure) and precision (the variance of v_p is zero for an exact estimate of m_p^*). In the meta-analysis, our data consist of observations of rates of return across different research programs. We would expect m_i^* for project i to differ from m_j^* for project j according to the different characteristics of the projects. The idea is to identify and account for those systematic differences. At the same time, characteristics of the program or the evaluation study will also affect the measurement errors v_p, and it is important to account for these effects as thoroughly as possible to get meaningful information on the determinants of the rate of return.

CHAPTER 5

A Model of the Determinants of Estimated Rates of Return to Agricultural R&D

Explanatory factors theorized to influence the size of the rate of return measure have been proposed throughout the previous chapters. This chapter brings together those theories in a more formal way to work toward a model of the rate of return with which we can confront the data set.

General Form of the Model

From Chapter 2, the factors that account for the variation in measured returns to agricultural R&D can be grouped into four broad categories:

- Characteristics of the rate of return measures (measure, *m*)
- Characteristics of the analysts performing the evaluation (analyst, **a**)
- Characteristics of the research being evaluated (research, **r**)
- Features of the evaluation (evaluation, **e**)

The general hypothesized functional relationship (f) between the rate of return measure (m) and the broad explanatory groups is

$$m = m^*(\mathbf{r}) + v(\mathbf{a}, \mathbf{r}, \mathbf{e}, u) = f(\mathbf{a}, \mathbf{r}, \mathbf{e}) + u,$$

where a bold letter indicates a vector of the corresponding characteristics. In other words, the measure m is equal to the true value of what was being evaluated m^* plus the measurement error v. The true measure m^* depends only on the characteristics of the research being evaluated, whereas the measurement error v depends on the same characteristics of the research but also on various other explanatory factors, as well as the truly random component u. In some instances it may be possible to identify a particular explanatory variable as being associated only with the true part, or only with the error part, of the measure, but in many cases a particular explanatory variable can be expected to play multiple roles.

For instance, suppose we use a dummy variable to distinguish "U.S. wheat research" from other research. We may expect that U.S. research into wheat has a relatively high return, because it is an important commodity and a crop characterized by significant rates of genetic improvement; that is, we may expect there to be a true, positive effect. On the other hand, we may expect there to be positive bias, too, because studies of wheat research may not have accounted well for the effects of U.S. wheat price supports and export subsidies, or spillover effects from CIMMYT research. Thus we cannot say a priori whether a high rate of return to wheat research is expected to be true or a result of bias. Alternatively the characteristic "basic research" might be expected to have an effect on the true rate of return but perhaps not have affected measurement error.

Although we can imagine a fully balanced data set, in which every observation of a rate of return matches meaningfully against observations of every element of the set of explanatory variables, we cannot have one in practice, for two reasons. One reason is a practical one. Not every study will provide all the information—for instance, some studies will not reveal whether or not the data were deflated or how the rate was calculated; whether the rate of return is real or nominal, or marginal or average, may not be knowable. The other reason is perhaps harder to deal with. Explanatory variables that are meaningful for some types of research evaluation studies are not meaningful for others. For instance, what is the relevant measure of the value of the industry for basic research or for research in the International Rice Research Institute that is targeted at the rice industry in some developing countries? Thus for certain subsets of the studies only certain subsets of the explanatory variables will pertain. Dealing properly with these aspects is a subject for the statistical procedures, discussed later.

Characteristics of the Rate of Return Measure (*m*)

In some meta-analyses, the results for each observation are dichotomous, "yes or no"–type outcomes. For instance, in medical research an issue may reduce to whether or not a particular treatment was effective. The results from benefit-cost analysis of agricultural R&D might be expressed this way for some purposes: was the NPV positive, the benefit-cost ratio greater than 1, or the IRR greater than a threshold value (say, the social opportunity cost of public funds, typically in the range of 3–5 percent per year)? And we could examine the variation in the frequency of these outcomes across different subsets of the data. Since the overwhelming majority of studies have found agricultural R&D to be successful according to these criteria, however, such an approach would not be particularly illuminating. Instead the outcome measure is a continuous variable, the IRR (rather than a discrete, dichotomous measure of profitability).

Studies vary in how they define and measure the IRR, so certain characteristics of the rate of return are relevant as explanatory variables to account for variation in rates of return among studies. These include whether it was real or nominal, marginal or average, ex ante or ex post, social or private. Finally we distinguish between whether the rate of return was synthesized by us (based on reported estimates of benefits versus corresponding research costs) or computed in the original study.

Analyst Characteristics (a)

The characteristics of the analyst may provide information on possible biases or precision, arising from the person or group who measures a rate of return having an interest in certain results from the study or having access to relatively good information about the research being evaluated. Some variation among studies may be associated with variations among individuals in what they work on, how they go about their work, and what procedures they use—details that may not be captured completely by our other proxies. This set of effects can be captured by a dummy to represent the particular individual or group.

The institutional affiliation (or employer) of the individual; the name, nationality, and other personal characteristics; and the date of the publication of the results provide information on the "school of thought" to which the individual belongs. This characteristic may be reflected in tendencies to compute higher or lower values for rates of return. Other relevant variables might include more specific measures of "school of thought," such as an indicator of whether the author was directly or indirectly affiliated with the University of Chicago, the University of Minnesota, or Australia (many of the studies have authors from one or more of these groups).[23] Another consideration is the degree to which the author specializes in the evaluation of agricultural R&D, which could be measured by comparing the number of his or her publications in this area to his or her total number of publications.

Whether or not the work represents a self-evaluation is an important factor that may tend to bias results favorably but, on the other hand, may also mean that the analyst is comparatively well informed. In many cases the rate of return to research expenditures is estimated by researchers associated in some way with the research or the research institution being evaluated. Although this may make no difference at all in the magnitude of the estimate, it is possible that, either consciously or unconsciously, a self-evaluation could introduce some upward bias in the estimate. Conversely a self-evaluator may better understand the research being evaluated or have better access to data and other information. This may reduce some biases, but the direction of any such effect is unclear.

A related issue is whether or not the work was published, and if it was, in what type of publication. These aspects will reflect the types of reviewer scrutiny to which the work was subjected, but the prepublication review process may also discriminate against studies that generate rates of return that fall outside the range of "conventional wisdom" prevailing in the profession at the time or that it may not be desirable to publish. There may be a type of selection bias involved here. A requirement

[23] Many of the contributions from other U.S. universities—North Carolina State, Iowa State, Yale, or the University of California at Berkeley and Davis—had their genesis at Chicago or Minnesota.

of a properly conducted meta-analysis is that considerable effort be made to ensure that all studies (both published and unpublished) have an equal likelihood of being selected, so as to reduce the influence of publication bias or the "file-drawer" problem. We suspect that some unpublished studies may have been left in the file drawer and not submitted for publication (or not accepted for publication) because the study results were not significant or were deemed inconclusive or "too small" (or too large) in some sense (Cook et al. 1992). Although we hypothesize that the outlet in which a study appears may explain some of the variation in the rate of return measures, we cannot assign an expected sign to the coefficient.

Research Characteristics (r)

The rate of return is likely to vary systematically with changes in the characteristics of the research itself. These characteristics include whether it is specific to (1) a particular field of science (for example, basic, applied, extension, all); (2) a particular commodity class (plants, animals, all); (3) a particular type of technology (yield enhancement, pest or disease control, management, postfarm handling); (4) the time period when the research being evaluated was conducted and when the results were adopted (which determines the time span of the flows of costs and benefits); (5) the geographical region where the R&D was conducted and (not the same thing) the geographical region where the results were adopted (especially important for international research centers, for instance); (6) the type of institution that conducted the R&D (university or research institute); and (7) the scope of the research being evaluated (an entire national agricultural research system, the entire portfolio for an institute, or a particular program or project).

Evaluation Characteristics (e)

As discussed earlier, several characteristics of the analysis have implications for the measure of the research-induced change in yield, productivity, or the supply shift; others have implications for the size of measured benefits and costs of R&D for a given research-induced supply shift. At a fundamental level such choices include whether the study involves an explicit economic surplus analysis, with a formal supply and demand model, or whether it leaves the model implicit and uses an approximation based on a percentage research-induced supply shift multiplied by the initial value of production (that is, kP_0Q_0).

Studies that use explicit surplus measures involve choices about the functional forms of supply and demand (linear or constant elasticity) and the nature of the supply shift, whether it was pivotal or parallel. Other market characteristics defined in such studies include whether it is open or closed to trade, and, relatedly, whether prices are endogenous or exogenous, undistorted or subject to government programs. Some studies use a market model that is disaggregated in a horizontal or vertical multimarket structure.

A further set of specification choices that have important implications for results relates to the research lag distribution, including its structure, shape, and length. These choices are often determined jointly (especially in econometric studies) with the size of the *k* shift (econometrically the lag structure defines the pattern of the shifts over time, and these are estimated jointly; in other studies the *k* shift may refer to a maximum shift, which is combined with adoption percentages in the lag profile to determine the entire distribution of supply shifts over time).

Some studies allow for spillover effects of research. Research conducted in one place, say California, may yield results that are adopted in other states or internationally (*spillouts*), which will increase global benefits, reduce California's benefits if California is an exporter of the affected commodity, and increase California's benefits for an imported good. Thus the theoretical effects on the rate of return of the consideration of spillouts in the analysis are ambiguous. Conversely California agriculture benefits from *spillins* of agricultural research results from other states and internationally, as well as nonagricultural research results, and an evaluation of the local returns to California's research may be biased upward if these spillins are inappropriately attributed to state research.

A final set of choices concerns what allowance is made for the effects of market distortions on the measures of benefits and costs. One such choice is whether to assume that a dollar of public expenditure on research costs society one dollar or, alternatively and following Fox (1985), to allow for the deadweight costs of taxation (δ cents per dollar of revenue raised) and charge $(1 + \delta)$ dollars of marginal social cost per dollar of government spending.[24] In addition some studies of research benefits allow for the effects of distorted exchange rates, government commodity programs, or environmental externalities. Allowing for the deadweight losses from taxation will reduce the rate of return, other factors held constant, while the effects of allowing for exchange rate distortions, commodity programs, or other distortions are less clear and will depend on other aspects of the analysis.

[24] See Fullerton (1991) and Ballard and Fullerton (1992) for views on the appropriate value for δ.

CHAPTER 6

The Evidence on Returns to Agricultural R&D

In Chapter 5 we developed a theoretical model of the determinants of estimated rates of return to research. The tabulations and figures in this chapter further define the sources of systematic variation in estimated rates of return to agricultural research and also indicate the nature of the data available for analysis. Before turning to a descriptive treatment of the data, we briefly describe the procedures used to compile the set of literature used in this meta-analysis.

Data Sources and Scoring Methods

In compiling our database of literature we tried to be as comprehensive as possible, while taking care to ensure that we did not introduce any known bias into the sample through the procedures used to construct it. We sought to obtain *every* published study from *every* country since Schultz (1953) through to 1997 (and a few more recent studies were included even though our exhaustive sample period was effectively "closed" at the end of 1996). We recognize that we cannot have done that, and that our sample is probably biased toward the United States.

We have been actively collecting the rate of return literature for over a decade. This collection formed the foundation of our database. To this foundation were added any additional studies identified in a database of references on the economic and policy aspects of agricultural R&D that had been developed over many years by Jeff Davis and was kindly made available to us, as well as the literature listed in the prior narrative reviews by Evenson, Waggoner, and Ruttan (1979), Echeverría (1990), and Alston and Pardey (1996). The studies cited in the literature included in these databases were also systematically scanned for additional rate of return studies, and every effort was made to obtain copies of these studies.

We also instigated a number of formal bibliometric searches. The CD-ROM version of the EconLit database compiled by the American Economic Association was searched for all relevant literature published during the period January 1969 to June 1997. Similarly the CD-ROM version of the AgECON literature database compiled by CAB International was searched for potentially relevant literature over the period January 1989 to June 1997.

Although a sizable number of rate of return studies have been published in reasonably accessible sources (such as refereed journals and books), a good deal of the work takes the form of discussion papers, working papers, and other forms of "gray" literature that are not as readily available. In recognition of this fact, we also contacted colleagues and professional acquaintances in Argentina, Australia, Brazil, Canada, Chile, China, Colombia, Egypt, India, Indonesia, Japan, Kenya, the Netherlands, Peru, the Philippines, Spain, the United Kingdom, the United States, and Uruguay, asking them to provide copies of relevant studies. Many of the international agricultural research centers have also committed significant resources to impact assessment studies. The appendix in Alston and Pardey (1995) provides a reasonably comprehensive listing of these studies, which was updated during the summer of 1997 by directly contacting colleagues working in these centers.

All the rate of return studies were assigned an identification number and entered in the set of literature used to construct our data set. A set of scoring sheets, detailing characteristics of studies as outlined in Chapter 5, was developed. Each study was reviewed and each estimated rate of return was recorded (most studies report more than one rate of return estimate) along with corresponding information, including (1) author details, including when and where the study was published; (2) institutional details of the agency doing the research being evaluated (for example, national government, near government, international, private); (3) aspects of the research being evaluated, including its focus (commodity orientation, natural resource focus), the period during which the research was performed, the nature of the technology (biological, chemical, mechanical), the nature of the R&D (basic, applied, extension), and the sector to which it applies (input supply, on-farm, postharvest); (4) country or regional focus; and (5) technical estimation details (nature of lag structure, lag length, inflation adjustment, method of estimation, and treatment of price distortions).[25] This information formed the data set described herein and analyzed in some detail in Chapter 7.

Characteristics of Studies and Evolution over Time

Publication Profile

We identified a total of 292 published studies reporting rate of return estimates and a total of 1,886 estimates: an average of 6.5 estimates per published study. About one-third of the publications compiled for our study are refereed journal articles (Table 2). More than 60 percent of the publications are discussion papers, working papers, reports, and various other types of gray literature. One of our objectives was

[25] Initially two coders scored an identical subset of studies and their results were compared. The degree of consistency between the two led us to conclude that coder bias would not be a problem, and one of the two then scored the entire data set.

Table 2—Publication patterns over time

Period	Number of publications		Number of observations		Observations per publication	
	Journal	Other	Journal	Other	Journal	Other
1958–69	3	3	8	23	2.7	7.7
1970–79	24	14	187	118	7.8	8.4
1980–89	38	46	264	383	6.9	8.3
1990–98	34	130	166	737	4.9	5.7
All observations	99	193	625	1,261	6.3	6.5

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.

to evaluate whether there are any significant differences in the rate of return evidence depending on the form in which it is published.[26]

The pace of publishing rate of return studies has picked up considerably over the years: each decade published at least twice as many as the previous one, a classic pattern for early-stage diffusion. During the period 1958–69 a total of 6 studies were published, an average of fewer than one publication per year. During 1970–79, 38 studies were published, at a rate of almost four per year, and during the next decade, 84 studies were published at a rate of more than eight per year. This grew to a total of 164 publications during the 1990–98 period, an average publication rate of almost 20 per year.

The balance of publication outlets has shifted, along with the rate of publication, and there appears to be faster growth in the gray literature. Much of the early literature was published in relatively formal outlets, perhaps because the first studies were breaking methodological ground or because gray literature was eventually published in more formal venues or lost. More recent studies have often been simply applications of methods developed 40 years ago, not suitable for publication in methodologically oriented journals.[27] The methodologically innovative work on the economic causes and consequences of research and technical change has moved away from the computation of rates of return, so that more often than not academic journal articles that relate to this area nowadays do not even report rates of return.

Characteristics of the Measure

Table 3 illustrates the patterns of numbers of published studies and rate of return estimates, grouped according to the different measures—real versus nominal, ex ante versus ex post, average versus marginal, private versus social. The preponderance of

[26] The presumption in this type of work to date has been that the variables on the right-hand side of the regression are exogenous. A related question is whether any aspects of the studies, especially the rate of return, can account for their publication fate. If so we may have a problem of simultaneous-equations bias.

[27] One can speculate that the demand for applied studies may be driven by pressures on funding, which seem to have grown, and this hypothesis could be evaluated by matching the data on studies to data on funding.

Table 3—Profile of rate of return measure characteristics

Characteristic	Number		Share of respective total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)[a]	
Real or nominal rate of return				
Nominal	66	410	22.6	21.7
Real	217	1,350	74.3	71.6
Unclear	16	126	5.5	6.7
Nature of evaluation				
Ex ante	54	406	18.5	21.5
Ex post	240	1,480	82.2	78.5
Average or marginal rate of return				
Average	205	1,097	70.2	58.2
Marginal	104	780	35.6	41.4
Unclear	2	9	0.7	0.5
Private or social rate of return				
Private	12	61	4.1	3.2
Social	288	1,825	98.6	96.8

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.
[a]Percentages in each section may not total 100 because categories are not always mutually exclusive. In particular, a single publication may provide multiple estimates from different categories.

studies report real social rates of return, obtained from ex post evaluations where average rates of return were measured.

Analyst Characteristics

Table 4 shows the numbers of published studies and rate of return estimates by different categories of analysts, grouped according to the type of agencies employing the first author. It can be seen that almost one-quarter of the studies (68 studies, 23 percent) were performed by government employees as first authors, but these produced only 18 percent of the estimates. University-employed first authors, mostly in U.S. land grant institutions, accounted for more than half of the studies (164 studies, 56 percent) and an even greater share of the estimates (1,287 estimates, 68 percent). The next largest group includes first authors who work at international research centers (including the centers of the Consultative Group on International Agricultural Research, or CGIAR) (*international researcher*) or at centers that fund international research, such as the Australian Centre for International Agricultural Research, an *international funder.* Together these account for 39 studies (13.3 percent) and 133 estimates (7.1 percent).

The same table also reports our division of the studies according to whether they can be regarded as self-evaluations or independent. This classification involved the exercise of some judgment on our part. It was decided, for instance, that studies carried out by analysts in an individual U.S. State Agricultural Experiment Station

Table 4—Profile of first author characteristics

Characteristic	Number		Share of respective total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)	
Employment (first author only)				
Government	68	330	23.3	17.5
University				
Non-U.S.	54	301	18.5	16.0
U.S. land grant	83	725	28.4	38.4
Other U.S.	27	261	9.2	13.8
International researcher	27	91	9.2	4.8
International funder	12	42	4.1	2.2
Private corporation	7	57	2.4	3.0
Unknown	14	79	4.8	4.2
Evaluator status				
Self-evaluation	80	298	27.4	15.8
Independent	156	1,174	53.4	62.2
Unclear	56	414	19.2	22.0

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.

(SAES) would be categorized as self-assessments if they considered just that SAES (for example, Alston, Pardey, and Carter 1994) but independent if they considered the entire SAES system (for example, Alston, Craig, and Pardey 1998). More than half (156 studies, 53.4 percent) are independent and account for 62.2 percent of the estimates, and over one-quarter of the studies are self-evaluations, but these account for only 16 percent of the estimates. For the remaining 56 studies there was not enough information to classify them clearly as either self-evaluations or independent.

Table 5 provides individual data for the fifteen most prolific publishers (as first, second, or third author) of rates of return studies. The top fifteen authors accounted for more than one-fifth of the total number of published rate of return studies and almost one-third of the rate of return estimates. The concentration among authors as sources of evidence is most pronounced for studies of rates of return to extension only, for which one author accounts for almost one-third of all the estimates in our sample.

Research Characteristics

Table 6 reports the numbers of publications and estimates according to the nature of the research being evaluated. The first category is *research orientation.* Very few studies evaluated basic research or extension; most computed returns to either all types of research or research and extension.[28] In terms of *research focus,* the lion's

[28] The distinctions between basic and applied research are not always clear. Rates of return were identified as applying to "basic" research only if reported as such by the authors of the evaluation studies; the default is "applied" research.

Table 5—Publications and numbers of rate of return observations by author

Auhor name[a]	Returns to: Research only	Returns to: Research and extension	Returns to: Extension only	All	Author's share of all
	(count)				(percentage)[b]
Publications					
R. Evenson	20	4	13	26	4.74
G. Norton	9	2	3	11	2.01
C. Thirtle	6	5	0	10	1.82
G. Scobie	7	2	0	9	1.64
A. Araji	6	4	0	8	1.46
A. Avila	7	2	1	8	1.46
G. Brinkman	7	1	0	8	1.46
J. Davis	7	0	0	7	1.28
G. Fox	7	0	0	7	1.28
G. Lubulwa	7	0	0	7	1.28
F. White	3	3	0	6	1.09
J. Alston	3	3	0	5	0.91
E. Da Cruz	5	0	0	5	0.91
L. Macagno	0	5	0	5	0.91
J. Mullen	4	2	1	5	0.91
Top 15	98	33	18	127	23.18
Total sample	372	213	44	548	100.0
Observations					
R. Evenson	155	23	40	218	6.23
A. Araji	79	62	0	141	4.03
G. Norton	96	39	3	138	3.94
G. Brinkman	66	18	0	84	2.40
G. Fox	66	0	0	66	1.89
C. Thirtle	47	16	0	63	1.80
J. Alston	22	34	0	56	1.60
G. Scobie	45	8	0	53	1.51
R. Sim	34	18	0	52	1.49
Y.-C. Lu	0	43	0	43	1.23
J. Mullen	30	11	2	43	1.23
P. Pardey	6	36	0	42	1.20
F. White	14	27	0	41	1.17
J. Leiby	40	0	0	40	1.14
G. Adams	40	0	0	40	1.14
Top 15	740	335	45	1,120	32.01
Total sample	2,149	1,225	125	3,499	100.0

Note: This table is based on the full sample of 292 publications reporting 1,886 observations. Of these, 35 publications (143 estimates) were excluded because "et al." was reported under author. Furthermore, 9 publications (32 estimates) were dropped because the reported rates of return were missing or indefinite (such as ">100 percent" or "<0 percent").

[a] Includes first, second, and third authors. The total number of observations adds to 3,499 because of counts of multiple authors—there were 1,854 first authors (292 publications), 1,232 second authors (195 publications), and 413 third authors (61 publications), adding to a total of 3,499 observations (548 publications).

[b] Percentages in each section may not total 100 because categories are not always mutually exclusive. In particular, a single publication may provide multiple estimates from different categories.

share concerned yield-enhancing R&D, followed by crop and livestock management and pest and disease management—but a particular study might be represented in two or even all three of these categories, since yield enhancement can come about through pest management or other aspects of management. But all three refer to on-farm technology; only 15 studies dealt with postfarm technology and another 7 with information, on- or off-farm related. Indeed, as can be seen by the classification according to *economic sector,* farming is the main focus; the studies of off-farm R&D are evenly divided between pre- and postfarm technology.

Table 6—Profile of research characteristics

Characteristic	Number		Share of total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)[a]	
Research orientation				
Basic research	10	32	3.4	1.7
Applied research	44	194	15.1	10.3
All research[b]	155	929	53.1	49.3
Research and extension	118	646	40.4	34.3
Extension	24	82	8.2	4.3
Unspecified	3	3	1.0	0.2
Research focus				
Yield enhancement	142	805	48.6	42.7
Crop and livestock management	95	585	32.5	31.0
Pest and disease management	76	479	26.0	25.4
Information	7	26	2.4	1.4
Postfarm	15	89	5.1	4.7
Other	39	175	13.4	9.3
Unspecified	91	678	31.2	35.9
Economic sector				
Farming	179	1,054	61.3	55.9
Processing	12	34	4.1	1.8
Inputs	15	59	5.1	3.1
General agriculture	89	671	30.5	35.6
Other	15	68	5.1	3.6
Research performer				
Government	229	1,323	78.4	70.1
University (except U.S. land grants)	28	175	9.6	9.3
U.S. land grants	44	438	15.1	23.2
International	27	62	9.2	3.3
Private	25	167	8.6	8.9
Other	10	40	3.4	2.1
Unspecified	29	250	9.9	13.3
Institutional orientation				
Project	57	293	19.5	15.5
Program	68	315	23.3	16.7
Institutionwide	25	166	8.6	8.8
Multi-institutional	149	1,112	51.0	59.0

(continued)

Table 6—Continued

Characteristic	Number		Share of total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)[a]	
Commodity focus				
Field crops[c]	165	985	56.5	52.2
Maize	37	184	12.7	9.8
Wheat	42	163	14.4	8.6
Rice	30	88	10.3	4.7
Livestock[d]	42	242	14.4	12.8
Crops and livestock	15	84	5.1	4.5
Tree crops	21	117	7.2	6.2
Natural resources[e]	15	79	5.1	4.2
All agriculture	57	355	19.5	18.8
Unclear	8	24	2.7	1.3

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.
[a] Percentages in each section may not total 100 because categories are not always mutually exclusive. In particular, a single publication may provide multiple estimates from different categories.
[b] Includes research not specified as either basic or applied.
[c] Includes all crops, barley, beans, cassava, sugar cane, groundnuts, maize, millet, other crops, pigeon pea or chickpea, potato, rice, sesame, sorghum, and wheat.
[d] Includes beef, swine, poultry, sheep or goats, all livestock, dairy, other livestock, pasture, and "dairy and beef."
[e] Includes fishery and forestry.

Among the *research performers,* government is the dominant category (229 studies), followed by universities (72 studies of research by U.S. land grant and other universities), while international research was evaluated in 27 studies (about 9 percent of the total). These categories all represent public research performers; only 25 studies evaluated privately performed research. More than half the studies did not provide detail on the *institutional orientation* of the research being evaluated: whether it was an individual project as part of a program, an entire program of research, or the research output of an entire institution.

Last, consider the *commodity focus.* Overwhelmingly evaluations relate to research into crops. More than half the estimates (165 studies, 985 estimates) are for field crops research (rice, wheat, and maize research accounts for almost one-quarter of the estimates). A mere 15 studies (79 estimates) reported returns to research with a natural resource focus (research into forestry, fisheries, soil, and so on).[29] It is also notable that a high proportion of the studies (about 78 percent) related to an identifiable commodity or equivalent focus, 57 studies related to all agriculture, and 8 left the focus undefined.

[29] This is not, of course, exactly the same thing as natural resource management research, which can have an agricultural commodity focus.

Table 7—Geographical characteristics of evaluated R&D

Characteristic	Number		Share of respective total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)	
Location of users				
Developed countries	125	1,014	42.8	53.8
North America	86	780	29.5	41.4
Europe	12	85	4.1	4.5
Other[a]	27	149	9.2	7.9
Developing countries	164	813	56.2	43.1
Africa	48	202	16.4	10.7
Asia and Pacific	56	312	19.2	16.5
Latin America and Caribbean	53	285	18.2	15.1
West Asia and North Africa	7	14	2.4	0.7
Multinational	16	44	5.5	2.3
Global	2	15	0.7	0.8
Location of performers				
Developed countries	132	1,032	45.2	54.7
North America	86	780	29.5	41.4
Europe	12	85	4.1	4.5
Other[a]	34	167	11.6	8.9
Developing countries	148	756	50.7	40.1
Africa	47	201	16.1	10.7
Asia	43	267	14.7	14.2
Latin America and Caribbean	52	277	17.8	16.7
West Asia and North Africa	6	11	2.1	0.6
Multinational	23	74	7.9	3.9
Global	7	24	2.4	1.3

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.
[a] Australia, Israel, Japan, and New Zealand.

Does the rate of return to R&D depend on where the research is carried out or where the results are adopted? These and other geographical aspects of research subject to evaluation are documented in Table 7. As it happens, in our data set most research was used where it was done, so this distinction is not very helpful. The data also can be used to assess the connection between investment in R&D and investment in R&D evaluation studies. For instance, the pattern of R&D evaluations across the developing regions of the world appears to be more uniform than the pattern of agricultural production and is not congruent with R&D spending. The users of the results of research that was evaluated are, perhaps surprisingly, more often found in developing countries (56.2 percent of the rate of return studies and 43.1 percent of the rates of return relate to R&D adopted in developing countries). This is especially so when the North American region—which is the user of the results of 29.5 percent of the research evaluated—is set aside. European users account for less than 5 percent of the research evaluated, other developed countries use only 9.2 percent, and developing countries use the rest.

Evaluation Characteristics

As discussed previously, method matters. There can be no doubt that choices of evaluation methodology have implications for results in rate of return studies. In particular, there is clear theoretical evidence that certain choices have particular effects (for example, choosing a pivotal supply shift cuts benefits in half relative to a parallel supply shift). As the theory has developed, so has the practice evolved.

Table 8 documents some primary modeling choices. A primary distinction is between rates of return derived from econometric models (especially in which the lag structure has been estimated econometrically) and those derived from explicit (or implicit) economic surplus models (in which the lag structure was assumed and imposed, along with other aspects). These are not mutually exclusive categories as some studies use both methods. A total of 99 studies used econometric estimates, but only eight of these simulated counterfactual research programs to generate rates of return; almost all deduced a rate of return analytically, as an algebraic transformation of estimated parameters. As shown by Alston, Norton, and Pardey (1995:200–6), the analytical approach is hard to get right. Some 1,147 estimates were based on some form of economic surplus; many (497) were based on a simple approximation originally proposed by Griliches (1958) (GARB = kP_0Q_0, as discussed previously). We can also

Table 8—Model specification characteristics, calculating benefits

Characteristic	Number		Share of respective total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)	
Modeling approach				
Econometric	99	733	33.9	38.9
Analytical	91	699	31.2	37.1
Simulated	8	34	2.7	1.8
Economic surplus	209	1,147	71.6	60.8
Implicit	90	497	30.8	26.4
Explicit	119	650	40.8	34.5
Unspecified	3	12	1.0	0.6
Number of markets, explicit				
Single	113	624	38.7	33.1
Multi-horizontal	6	16	2.1	0.8
Multi-vertical	5	21	1.7	1.1
Unclear	1	1	0.3	0.1
Trade structure, explicit surplus model				
Closed	68	386	23.3	20.5
Open				
Large	17	53	5.8	2.8
Small	52	222	17.8	11.8
Unclear	1	1	0.3	0.1

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.

see from the table that almost all the research evaluation studies that specified market models (that is, among the explicit economic surplus studies) have been single-market studies; the multimarket studies were both horizontally and vertically disaggregated. Furthermore, the majority used closed economy models or a simple small country model. Only 17 studies allowed for an effect of research on world trading prices.

A key determinant of the estimate of the annual benefits from adoption of a new technology is the measure of the research-induced shift in supply (or increase in productivity), sometimes referred to as *k*. Table 9 shows the distribution among studies of methods for estimating this shift. Among the 130 studies using econometric methods, 99 (76 percent) used production functions or productivity functions. Among the 175 studies using noneconometric methods, more than half used experimental yields, and a further one-quarter used industry yields. Only a handful of studies allowed for spillins and spillouts of research effects in the computation of rates of return.

As argued by Alston and Pardey (1996:214–216 and 219–227) and demonstrated by Alston, Craig, and Pardey (1998), the research lag structure can have a profound influence on the estimated rate of return to research. In a noneconometric analysis, excessive truncation of the lag will reduce the rate of return because some future ben-

Table 9—Supply shifts used to estimate benefits, study characteristics

Characteristic	Number		Share of respective total	
	Publications	Estimates	Publications	Estimates
	(count)		(percentage)	
Econometric approach	130	969	43.2	48.4
Production	55	413	18.8	21.9
Productivity	44	335	15.1	17.8
Cost	7	51	2.4	2.7
Supply	18	110	6.2	5.8
Nonparametric	2	4	0.7	0.2
Other[a]	11	60	3.8	3.2
Noneconometric approach	175	917	59.9	48.6
Experimental yields	93	460	31.9	24.4
Industry yields	47	204	16.1	10.8
Experimental productivity	5	89	1.7	4.7
Other[b]	46	203	15.8	10.8
Incremental costs included	81	487	27.7	25.8
Spillovers[c]				
Spillins	41	324	14.0	17.2
Spillouts	11	94	3.8	5.0
No spillovers	257	1,486	88.0	78.8

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.
[a] Supply shift calculated from estimates of a profit function or input demand function, or by other means.
[b] Supply shift calculated by other means (for example, direct measurement) or by cost reduction.
[c] Some estimates have spillover effects both ways.

efits will be ignored; in an econometric study, however, the opposite can (and indeed does) happen, because larger short-term benefits are estimated when a (probably inappropriately) truncated lag is used, and these predominate. As can be seen in Table 10, many studies (nearly two-thirds of all the studies, reporting more than half the estimates) do not even clearly specify this element. Polynomial lags are the most frequent choice in those studies that do specify the lag structure. It is interesting to note that of the 876 estimates with an explicit research lag structure, more than one-third (338 estimates) did not include any gestation lag between the time when research expenditure is incurred and the time when the resulting benefits begin to flow. Perhaps the most important difference among the studies, however, is the lag length; among the studies that used an explicit lag structure, most used research lag lengths of less than 20 years. Extension lag lengths were even shorter; most were less than 10 years.

Table 10—Modeling lag structures, study characteristics

	Number[a]		Share of total[b]	
Characteristic	**Publications**	**Estimates**	**Publications**	**Estimates**
	(count)		(percentage)	
Without explicit lag shape[c]	**182**	**1,003**	**62.3**	**53.2**
Research only	119	549	40.8	29.1
Research when extension is included	177	988	60.6	52.4
Extension only	5	15	1.7	0.8
Extension when research is included	63	454	21.6	24.1
Research and extension	81	439	27.7	23.3
With explicit lag shape	**119**	**883**	**40.8**	**46.8**
Research lag structure	116	876	39.7	46.4
Polynomial (second-order)	42	284	14.4	15.1
Polynomial (higher-order)	3	11	1.0	0.6
Trapezoidal	12	73	4.1	3.9
Free-form	4	6	1.4	0.3
Inverted V	8	52	2.7	2.8
Unspecified, unclear, or other[d]	68	457	23.3	24.2
Research lag length	148	876	50.7	46.4
0–10 years	43	285	14.7	15.1
11–20 years	48	256	16.4	13.6
21–30 years	15	68	5.1	3.6
31–40 years	13	78	4.5	4.1
>40–∞ years	6	29	2.1	1.5
∞ years	14	74	4.8	3.9
Unspecified or unclear[e]	12	93	4.1	4.9
Research gestation lag	126	876	43.2	46.4
Included	73	530	25.0	28.1
Omitted	50	338	17.1	17.9
Unspecified or unclear[f]	3	8	1.0	0.4

(continued)

Table 10—Continued

Characteristic	Number[a] Publications	Number[a] Estimates	Share of total[b] Publications	Share of total[b] Estimates
	(count)		(percentage)	
Extension lag structure	73	416	25.0	22.1
Polynomial (second-order)	21	102	7.2	5.4
Polynomial (higher-order)	1	3	0.3	0.2
Trapezoidal	4	6	1.4	0.3
Free-form	3	5	1.0	0.3
Inverted V	2	3	0.7	0.2
Unspecified, unclear, or other[g]	106	764	36.3	40.5
Extension lag length	88	528	30.1	28.0
0–10 years	51	385	17.5	20.4
11–20 years	16	72	5.5	3.8
21–30 years	5	9	1.7	0.5
31–40 years	2	8	0.7	0.4
>40–∞years	2	6	0.7	0.3
∞ years	9	34	3.1	1.8
Unspecified or unclear[h]	57	369	19.5	19.6

Note: This table is based on the full sample of 292 publications reporting 1,886 observations.
[a] Counts do not total to the respective subtotals because categories are not always mutually exclusive.
[b] Percentages represent share of total number of publications (292) and total number of estimates (1,886) with the respective attribute.
[c] Includes 2 publications (2 estimates) with unspecified research lag length.
[d] Includes 3 publications (7 estimates) in which there were no attempts to specify the type of lag structure used, 5 publications (48 estimates) with an unclear lag structure, and 60 publications (402 estimates) with "other" lag type.
[e] Includes 3 publications (7 estimates) in which there were no attempts to specify the type of lag structure used and 9 publications (86 estimates) with an unclear lag length.
[f] Includes 1 publication (6 estimates) with unspecified gestation lag length and 2 publications (2 estimates) for which the reported lag length was unclear.
[g] Includes 64 publications (467 estimates) in which there were no attempts to specify the type of lag structure used, 2 publications (3 estimates) with an unclear lag structure, and 36 publications (279 estimates) with "other" lag type.
[h] Includes 54 publications (355 estimates) in which there were no attempts to specify the type of lag structure used and 4 publications (14 estimates) with an unclear lag structure.

Modeling choices have evolved over the 40-year history of studies of rates of return to agricultural R&D (Table 11). In the early years, only six studies (31 estimates) were conducted, so we focus on the decades after that, beginning with 1970–79. Roughly equal shares of studies have continued to use econometric and noneconometric methods to measure research-induced supply shifts. The share of studies using 31–40 years of lags has grown, mostly at the expense of studies using 21–30 or more than 40 years of lags; the fraction of studies using 11–30 years of lags has remained fairly constant at around 50 percent. On the whole there has not been much clear evolution in the lengths of the lag structures being used. There has been more

Table 11—Orientation of evaluation methodologies, 1958–98

Characteristic	Number of estimates	1958–69	1970–79	1980–89	1990–98	1958–98
	(count)	(percentage)				
Supply shift						
Econometric	969	67.7	48.5	53.2	50.5	51.4
Noneconometric	917	32.3	51.5	46.8	49.5	48.6
Lag length (benefits)[a]						
0–10 years	253	9.7	6.2	17.9	12.7	13.4
11–20 years	537	41.9	22.0	38.8	22.8	28.5
21–30 years	376	0	20.7	12.2	25.9	19.9
31–40 years	178	0	4.3	5.6	14.3	9.4
>40–∞ years	141	0	9.5	6.6	7.6	7.5
∞ years	102	35.5	7.5	2.9	5.4	5.4
Unspecified[b]	109	12.9	13.1	3.2	4.9	5.8
Unclear[c]	190	0	16.7	12.7	6.3	10.1
Lag shape (benefits)[a]						
Polynomial (second-order)	277	0	15.1	22.4	9.5	14.7
Polynomial (higher-order)	3	0	0	0	0.3	0.2
Trapezoidal	53	0	0	1.1	5.1	2.8
Free-form	5	0	0	0	0.6	0.3
Inverted V	131	35.5	4.6	13.1	2.3	6.9
Other	249	19.4	1.3	9.1	20	13.2
Unspecified[d]	1,091	45.2	70.5	53.5	57.2	57.9
Unclear[e]	76	0	8.5	0.8	5.0	4.0

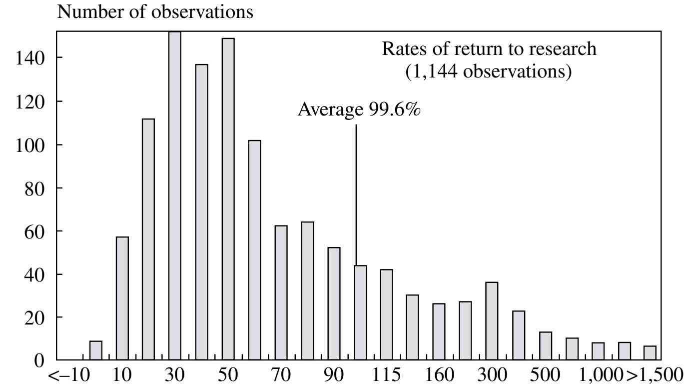
Note: This table is based on the full sample of 292 publications reporting 1,886 observations.
[a]Research only, but includes implicit lags, that is, methods that matched the cost and benefit streams.
[b]Unspecified estimates are those for which the research lag length is not made explicit.
[c]Lag length is unclear.
[d]Unspecified estimates are those for which the type of lag structure is not made explicit.
[e]Unclear lag structure.

movement in the lag shapes, with a progressive abandonment of the inverted V shape and the progressive introduction of polynomial and then trapezoidal lags.

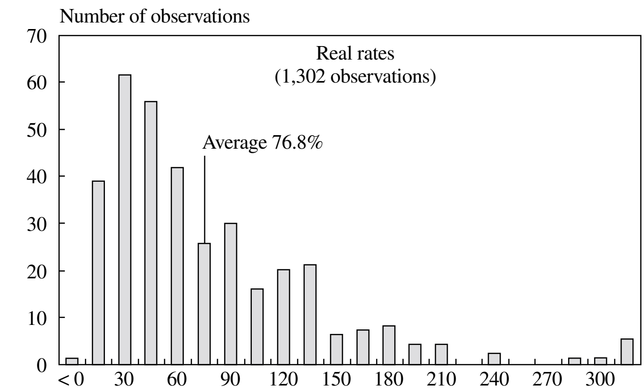
Patterns of Rates of Return

We turn now to a consideration of the rates of return themselves and how they varied with the characteristics of the studies, the analysts, the nature of research evaluated, and so on. The *original* full sample included 292 publications reporting 1,886 observations. Of these, 9 publications were dropped because, rather than specific rates of return, they reported results such as ">100 percent" or "<0." As a result of these and other exclusions for similar reasons, 32 observations were lost. Of the remaining 1,854, 2 observations were dropped as extreme outliers, which left a maximum of 1,852 observations that we regarded as useful for analysis; we refer to these as the "full sample."

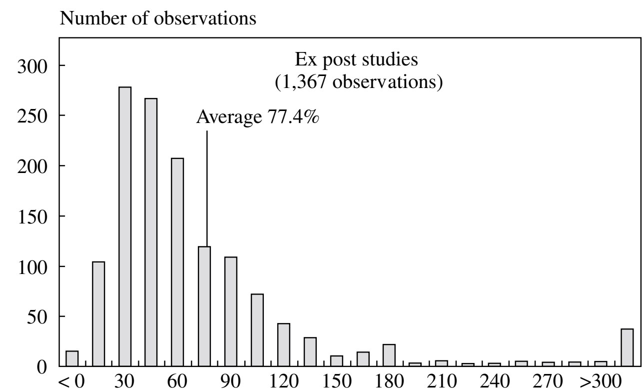
Figure 3—Distributions of rates of return to agricultural R&D



(a) Rates of return to research (%)

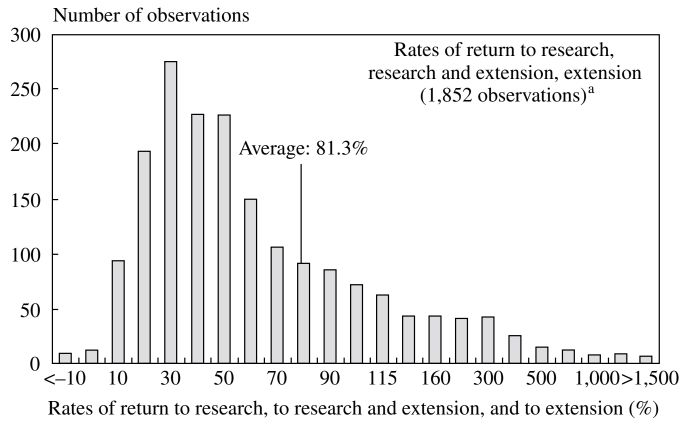


(b) Rates of return to research and to research and extension (%)

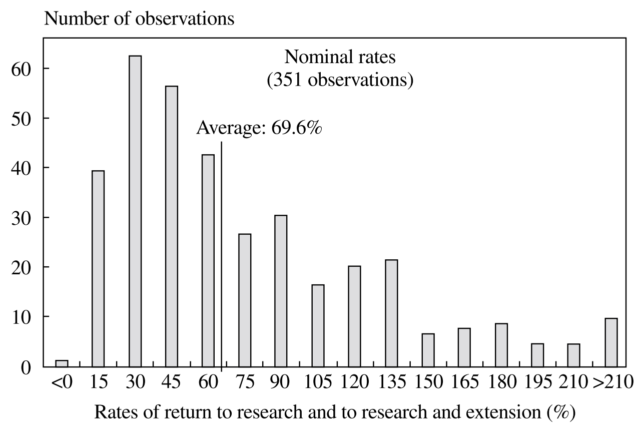


(c) Rates of return to research and to research and extension (%)

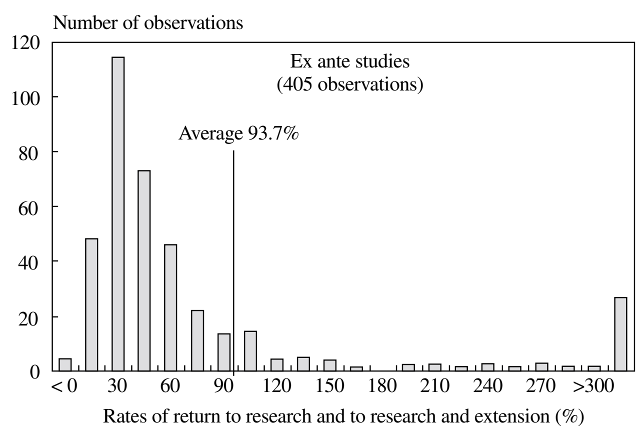
Note: Distributions are drawn from the full sample of 1,886 observations but exclude two extreme outliers.
[a]See notes to Table 12.



Number of observations
300
250
200
150
100
50
0
Rates of return to research,
research and extension, extension
(1,852 observations)a
Average: 81.3%
<–10
10
30
50
70
90
115
160
300
500
1,000
>1,500
Rates of return to research, to research and extension, and to extension (%)



Number of observations
60
50
40
30
20
10
0
Nominal rates
(351 observations)
Average: 69.6%
<0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
>210
Rates of return to research and to research and extension (%)



Number of observations
120
100
80
60
40
20
0
Ex ante studies
(405 observations)
Average 93.7%
< 0
30
60
90
120
150
180
210
240
270
>300
Rates of return to research and to research and extension (%)

Ranges of Rates of Return

Figure 3 shows the distribution of the full sample of 1,852 rates of return to agricultural R&D. Panel (a) includes frequency distributions of all observations and observations for research only; panel (b) partitions the sample into nominal and real rates of return; panel (c) distinguishes between ex ante and ex post rate of return estimates. One feature of the evidence on rates of return is the relatively small signal-to-noise ratio. The rates of return range from small negative numbers to an extreme and implausible rate of more than 700,000 percent per year.[30] Only a small fraction of the data (fewer than 25 percent of the estimates) actually falls within the oft-cited 40–60 percent per year range. The wide range might reflect differences among typical rates of return among different sets of studies—differences among groups such as applied versus basic research, or research on natural resources versus commodities. Unfortunately, however, the range of rates of return is similarly large within the primary groups of studies of interest here; the large range reflects variation *within* more than *among* groups. This large within-group variation makes it more difficult to discern statistically significant differences among groups.

To reduce the role of noise in masking the information content of the data, in the regression analysis (reported in Chapter 7) we discarded a further 30 outliers using statistical methods. In addition, for the regression analysis a further 694 observations had to be dropped because they failed to include information on all the explanatory variables to be included in the model, leaving 1,128.[31] Hence the number of observations used in the econometric analysis, and used in the tables summarizing rate of return evidence, is smaller than the corresponding sample size in the tabulated descriptive analysis reported previously.

Table 12 provides summary statistics on the distributions of rates of return to research, extension, and both research and extension for both the full data set and the data set used in the regression analysis. The overall average rate of return across all 1,128 observations used in the regression was 65 percent per year, with a standard deviation of 86 percent. In this sample, the estimated annual rates of return averaged 80 percent for research only, 80 percent for extension only, and 47 percent for research and extension combined. These statistics are similar to their counterparts for the full sample. The overall mean rate of return across all 1,852 observations was 81

[30] Investing $1 at an internal rate of return of 700,000 percent per year would generate $7,000 after one year, $49 million after two years, $343 billion after three years, and $2,401 trillion after four years. The gross domestic product (GDP) of the world in 1997 was $29.0 trillion. Suppose the investment of $1.21 billion in 1980 in U.S. public agricultural R&D had earned an IRR of 50 percent per year, the midpoint of the conventional wisdom (for example, Fuglie et al. 1996) and close to the mean for aggregate U.S. studies in the data set used in the regression analysis (48 percent per year). The accumulated stream of benefits would be worth $4 trillion (1980 dollars) by the year 2000—about 30 years' worth of U.S. agricultural GDP. The same amount invested at 8 percent per year (for example, Alston, Craig, and Pardey 1998) would be worth $6 billion (1980 dollars) in 2000—more plausible and still a good investment.

[31] The mean rate of return for the 30 statistical outlier observations was 885 percent. The mean for all 758 (694 + 32 + 2 + 30) discarded observations was 1,732 percent, and the range was from −56.6 percent to 724,323 percent per year.

Table 12—Ranges of rates of return

Sample	Number of observations	Rate of return Mean	Mode	Median	Minimum	Maximum
	(count)	(percentage)				
Full sample[a]						
Research only	1,144	99.6	46.0	48.0	–7.4	5,645
Extension only	80	84.6	47.0	62.9	0	636
Research and extension	628	47.6	28.0	37.0	–100.0	430
All observations	1,852	81.3	40.0	44.3	–100.0	5,645
Regression sample[b]						
Research only	598	79.6	26.0	49.0	–7.4	910
Extension only	18	80.1	91.0	58.4	1.3	350
Research and extension	512	46.6	28.0	36.0	–100.0	430
All observations	1,128	64.6	28.0	42.0	–100.0	910

[a] The original full sample included 292 publications reporting 1,886 observations. Of these, 9 publications were dropped because rather than specific rates of return they reported results such as ">100 percent" or "<0." As a result of these exclusions, 32 observations were lost. Of the remaining 1,854, two observations were dropped as extreme (and influential) outliers. These two estimates were 724,323 percent and 455,290 percent per year.

[b] Excludes outliers and observations that could not be used in the regression owing to incomplete information on explanatory variables. See text.

percent per year (the rate of return averaged 100 percent for research only, 85 percent for extension only, and 48 percent for research and extension combined). Both Table 12 and Figure 3 illustrate the generally wide spread within each category, as well as the positively skewed nature of the distributions.

Rates of Return by Measure Attributes

Theory and conventional wisdom suggest that rates of return should vary according to characteristics of the measures. Nominal rates of return would be expected to be higher than real rates, everything else equal. Ex post estimates might be higher or lower than ex ante estimates, but selection bias in ex post studies might mean they find higher rates of return. Diminishing returns would suggest that marginal rates of return are lower than average rates of return, and it is commonly held that private rates of return are lower than their public counterparts. Table 13 compares the distributions of rates of return estimates according to these measure attributes.

Rates of Return by Author

As we have already seen, a small number of authors has contributed disproportionately to the total body of evidence on the returns to agricultural R&D. Table 14 shows

Table 13—Rates of return by measure attributes

Attribute	Number of estimates	Rate of return: Average	Mode	Median	Minimum	Maximum
	(count)	(percentage)				
Real or nominal rate of return						
Nominal	351	69.6 (64.1)	52.0	51.0	–2.3	466
Real	1,302	76.8 (145.8)	46.0	43.8	–100.0	1,736
Nature of evaluation						
Ex ante	405	93.7 (214.7)	49.0	35.9	–12.3	1,736
Ex post	1,367	77.4 (216.5)	46.0	46.0	–100.0	5,645
Average or marginal rate of return						
Average	1,708	81.5 (266.0)	49.0	38.0	–100.0	5,645
Marginal	686	80.5 (97.8)	40.0	50.0	–1.0	1,219
Private or social rate of return						
Private	55	138.5 (499.8)	20.0	30.0	0.0	3,539
Social	1,717	79.3 (200.6)	40.0	44.3	–100.0	5,645
Benefit-cost ratio						
Reported	1,683	72.4 (199.5)	46.0	44	–100.0	5,645
Derived	89	246.7 (387.2)	1.4	60	0.3	1,720

Notes: Standard deviations are given in parentheses. Sample excludes two outliers and includes only returns to research only and combined research and extension, so that the maximum sample size is 1,772. In some instances further observations were lost owing to incomplete information on the specific characteristics of interest.

the distributions of rate of return estimates published by the top 15 individuals as first, second, or third authors of studies. The means and ranges can be unduly distorted by extreme observations. In this context, the median might be a better measure of central tendency. Six of these individuals have medians exceeding 60 percent per year and two, more than 100 percent per year. Four individuals have medians less than or equal to 25 percent. One implication is that variation among individual analysts (perhaps in terms of their choices of methods) might have contributed much to the overall variation, an outcome that is making it difficult to discern other differences.

Table 14—Rates of return by author

Author	Number of observations	Rate of return Mean	Median	Minimum	Maximum
	(count)	(percentage)			
R. Evenson	218	80.4	62.3	0	350.0
A. Araji	141	43.2	36.0	1.1	191.0
G. Norton	138	8,811.8	54.0	3.0	724,323.0
G. Brinkman	84	75.4	71.6	20.0	130.6
G. Fox	66	77.2	79.5	20.0	130.6
C. Thirtle	63	113.0	72.4	0	1,219.0
J. Alston	56	28.5	19.1	–1.0	260.0
G. Scobie	53	34.0	22.6	2.5	101.0
R. Sim	52	38.3	36.6	1.4	104.8
Y.-C. Lu	43	53.0	41.0	14.3	169.0
J. Mullen	43	87.3	25.0	2.5	562.0
P. Pardey	42	42.4	22.3	–1.0	260.0
F. White	41	65.4	57.0	6.9	169.0
J. Leiby	40	201.1	150.5	22.6	729.7
G. Adams	40	201.1	150.5	22.6	729.7
Top 15	1,120	1,151.9	52.0	–1.0	724,323.0
Total sample	3,499	754.2	44.0	–100.0	724,323.0

Note: See notes to Table 5.

Rates of Return by Research Focus

A primary issue for this study is the comparison of rates of return to research among different categories of research, and in particular the rates of return to research on natural resource management issues. Table 15 summarizes the distributions of rate of return estimates according to the "commodity" orientation of the research being evaluated.

A total of 1,772 rates of return are included. The mean is 81 percent per year, and the range is from –100 to 5,645 percent per year. Again the median might be more meaningful, and it is 44 percent per year. Over half of these rates of return (916 estimates) are for *crops* research, for which the distribution of rates of return is similar to that for the entire sample (although, within that group, the results for wheat show a lower mean and a narrower range). Another quarter of the rates of return (436) are for studies of research affecting multiple commodities, and again the distribution of rates of return is similar to that for the entire sample, as is also broadly true for the 233 rates of return to *livestock* research. Some more substantial differences can be seen in the distribution of rates of return for *resources* research (78 rates of return

Table 15—Rates of return by commodity orientation

Commodity orientation	Number of observations	Rate of return: Mean	Mode	Median	Minimum	Maximum
	(count)	(percentage)				
Multicommodity[a]	436	80.3 (110.7)	58.0	47.1	–1.0	1,219.0
All agriculture	342	75.7 (110.9)	58.0	44.0	–1.0	1,219.0
Crops and livestock	80	106.3 (115.5)	45.0	59.0	17.0	562.0
Unspecified[b]	14	42.1 (19.8)	16.4	35.9	16.4	69.2
Field crops[c]	916	74.3 (139.4)	40.0	43.6	–100.0	1,720.0
Maize	170	134.5 (271.2)	29.0	47.3	–100.0	1,720.0
Wheat	155	50.4 (39.4)	23.0	40.0	–47.5	290.0
Rice	81	75.0 (75.8)	37.0	51.3	11.4	466.0
Livestock[d]	233	120.7 (481.1)	14.0	53.0	2.5	5,645.0
Tree crops[e]	108	87.6 (216.4)	20.0	33.3	1.4	1,736.0
Resources[f]	78	37.6 (65.0)	7.0	16.5	0.0	457.0
Forestry	60	42.1 (73.0)	7.0	13.6	0.0	457.0
All studies	1,772	81.2 (216.1)	46.0	44.0	–100.0	5,645.0

Notes: See notes to Table 12. Standard deviations are given in parentheses. Sample excludes two extreme outliers and includes only returns to research only and combined research and extension, so that the maximum sample size is 1,772. In some instances further observations were lost owing to incomplete information on the specific characteristics of interest.

[a] Includes research identified as "all agriculture" or "crops and livestock," as well as "unspecified."

[b] Includes estimates that did not explicitly identify the commodity focus of the research.

[c] Includes all crops, barley, beans, cassava, sugar cane, groundnuts, maize, millet, other crops, pigeon pea or chickpea, potato, rice, sesame, sorghum, and wheat.

[d] Includes beef, swine, poultry, sheep or goats, all livestock, dairy, other livestock, pasture, dairy, and beef.

[e] Includes "other tree" and "fruit and nuts."

[f] Includes fishery and forestry.

with a mean of 38 percent per year, and a median of 17 percent per year). This category is mostly forestry research, for which the research lags might be expected to be relatively long, and this alone could account for the relatively low average rates of return. A similar story might account for the low median rate of return for tree crop research.

Research Lags and Research Returns

Theory, informal impressions, and anecdotal evidence suggest that the estimated rates of return to research are likely to have been affected by decisions made by analysts about the specification of the lag structure. As discussed earlier, the nature and magnitude of these effects are expected to be different between econometric and noneconometric studies. Table 16 first summarizes the rates of return from econometric studies, according to the form of lag and then, within forms, the lag length; next the same structure is followed for noneconometric studies.

Consider first the *econometric* studies. There are few clear patterns among the rates of return. One can see some tendency for the average rates of return to become smaller with longer lag lengths within some forms of lags, although this is not always the case. Free-form and polynomial lag structures have tended to yield lower rates of return than trapezoidal and inverted V structures.

Next consider the *noneconometric* studies. These studies have tended to yield lower average rate of return estimates than the econometric studies, reflecting in particular lower values for the highest estimated rates of return. Again there is some tendency for the average rates of return to become smaller with longer lag lengths, but when all forms are combined the distribution of rates of return according to lag length shows no clear pattern. The rates of return were generally lower when an explicit structure for supply and demand was employed.

Rates of Return by Geographical Region of Research Performer

Table 17 groups the data according to the geographical region of the agency that performed the research. Although the mean of the rate of return estimates for developed countries is higher than that for developing countries (98 versus 60 percent per year), the medians are virtually identical (46 versus 43 percent per year) and little different from the median for research done by the international centers (40 percent). Within regions, too, it is difficult to discern any meaningful patterns, but by all the measures the estimated rates of return tended to be lower in Africa and West Asia–North Africa than in Latin America and the Caribbean or Asia; similarly the estimated rates of return tended to be higher in Europe and North America than in Australasia and other developed countries.

Throughout the tabular comparisons of rates of return in this chapter, the spread of rates of return (the *within-group* variation) in the distribution made it difficult to

Table 16—Lag length, lag structure, and the returns to R&D

Type of lag specified	Lag: Mean	Lag: Length	Number of estimates	Rate of return: Mean	Mode	Median	Minimum	Maximum
	(years)		(count)			(percentage)		
Econometric								
Polynomial	13.2	0–∞	285	79.9	58.0	58.0	4.5	729.7
	11.0	<15	225	88.6	58.0	64.3	6.9	729.7
	17.7	15–30	51	49.8	15.0	39.0	8.1	260.0
	45.0	>30	9	34.7	4.5	9.3	4.5	140.0
	Unspecified		7	35.4	19.0	33.0	19.0	55.0
Trapezoidal	32.7	0–∞	55	97.7	95.0	67.0	11.0	384.4
	26.9	15–30	12	102.8	95.0	95.0	19.6	218.2
	34.3	>30	43	96.3	45.0	62.0	11.0	384.4
Free-form[a]	28.0	0–∞	6	26.5	6.0	30.0	6.0	45.0
	23.3	15–30	3	22.3	6.0	27.0	6.0	33.9
	35.0	>30	3	30.7	14.0	33.0	14.0	45.0
Inverted V	12.0	0–∞	33	134.5	30.0	72.0	23.0	562.0
	10.5	<15	28	151.0	50.0	88.0	30.0	562.0
	15.8	15–30	4	36.2	23.0	34.5	23.0	52.6
	40.0	>30	1	65.0	65.0	65.0	65.0	65.0
	Unspecified		17	75.7	95.0	70.6	45.0	130.0
Other[a]	13.3	0–∞	304	75.6	46.0	48.0	–1.0	1,219.0
	0.0	0	30	48.6	31.0	44.4	25.2	111.0
	7.9	>0 and <15	147	96.7	29.0	55.0	0.0	1,219.0
	25.1	15–30	63	53.7	46.0	47.0	4.5	151.0
	35.1	>30	64	61.2	40.0	44.1	–1.0	260.0
	Unspecified		20	127.4	19.0	110.0	19.0	337.0
No structure	26.6	0–∞	79	45.8	54.0	51.0	0.3	185.0
	0.0	0	6	44.9	20.9	41.9	20.9	76.8
	12.8	>0 and <15	8	60.4	23.0	61.5	23.0	91.0
	22.8	15–30	41	67.0	54.0	60.0	11.9	185.0
	44.5	>30	24	5.0	0.3	2.1	0.3	46.0

		Unspecified	31	40.4	27.0	36.0	9.0	125.0
Unclear		Unspecified	50	31.7	27.0	33.0	8.9	60.0
All forms[a]	16.3	0–∞	762	77.9	58.0	53.0	–1.0	1,219.0
	0.0	0	36	48.0	46.0	44.4	20.9	111.0
	9.9	>0 and <15	408	95.2	58.0	60.7	0.0	1,219.0
	22.3	15–30	174	58.1	46.0	49.9	4.5	260.0
	38.0	>30	144	60.1	40.0	41.6	–1.0	384.4
		Unspecified	100	60.0	27.0	41.2	8.9	337.0
Noneconometric								
Explicit structure[a]	36.7	0–∞	38	19.7	14.0	18.5	–14.9	71.0
	9.3	<15	9	35.9	29.0	29.0	14.0	71.0
	17.0	15–30	1	14.0	14.0	14.0	14.0	14.0
	50.0	>30	28	14.7	2.5	16.5	–14.9	26.7
No structure[a]	24.0	0–∞	740	98.1	49.0	38.0	–100.0	5,645.0
	0.0	0	2	17.5	17.0	17.5	17.0	18.0
	10.5	>0 and <15	194	55.6	37.0	41.2	–100.0	457.0
	23.5	15–30	394	139.5	49.0	42.6	–2.3	5,645.0
	43.5	>30	150	45.5	20.0	29.0	0.0	301.0
		Unspecified	132	38.9	1.4	31.7	1.1	191.0
All forms[a]	24.5	0–∞	778	94.3	30.0	23.0	–100.0	5,645.0
	0.0	0	2	17.5	17.0	17.5	17.0	18.0
	10.4	>0 and <15	203	54.8	42.0	40.0	100.0	457.0
	23.5	15–30	395	139.1	49.0	42.5	2.3	5,645.0
	44.3	>30	178	40.7	20.0	25.8	–14.9	301.0
		Unspecified	132	38.9	1.4	31.7	1.1	191.0
All models[a]	20.5	0–∞	1,540	86.2	49.0	45.9	–100.0	5,645.0
	0.0	0	38	46.4	46.0	43.0	17.0	111.0
	10.1	>0 and <15	611	81.8	58.0	53.5	–100.0	1,219.0
	23.1	15–30	569	114.4	49.0	46.0	2.3	5,645.0
	41.9	>30	322	49.3	20.0	30.0	–14.9	384.4
		Unspecified	232	48.0	27.0	35.4	1.1	337.0

Notes: See notes to Table 12. Sample excludes two extreme outliers and includes only returns to research only and combined research and extension, so that the maximum sample size is 1,772. In some instances further observations were lost owing to incomplete information on the specific characteristics of interest.

[a] Represents the mean length of the R&D lags for rate of return estimates based on finite lag structures. Under the econometric approach, one of the 6 *Free-form* estimates is based on an infinite lag structure, as are 43 of the 304 *Other* estimates and 44 of the 762 *All forms* estimates. Under the noneconometric approach, 8 of the 38 *Explicit structure* estimates are based on an infinite lag structure, as are 5 of the 740 *No structure* estimates, 13 of the 778 *All forms* estimates, and 57 of the 1,540 *All models* estimates.

discern clear patterns of differences among groups. A multivariate analysis might find some significant differences (for example, among commodity areas) after having controlled for other important sources of variation. In the next chapter, a regression model is used to isolate particular influences.

Table 17—Rates of return by geographical region of research performer

Geographical region	Number of estimates	Rate of return Mean	Mode	Median	Minimum	Maximum
	(count)			(percentage)		
Developed countries	990	98.2 (278.1)	19.0	46.0	–14.9	5,645
North America[a]	740	102.4 (306.9)	22.0	46.5	–14.9	5,645
Europe	85	93.9 (152.0)	19.0	62.2	0.0	1,219
Australasia[b]	154	83.7 (177.9)	20.0	28.7	–1.3	1,736
Other developed countries[c]	11	55.6 (36.1)	22.2	37.4	22.2	125
Developing countries	683	60.1 (84.1)	46.0	43.0	–100.0	1,490
Africa	188	49.6 (113.0)	10.9	34.3	–100.0	1,490
Asia and Pacific	222	78.1 (93.2)	49.0	49.5	6.0	1,000
Latin America and Caribbean	262	53.2 (39.3)	46.0	42.9	3.0	325
West Asia and North Africa	11	44.2 (19.6)	28.0	36.0	28.0	80
Multinational	74	58.8 (98.3)	32.0	34.0	–47.5	677
International agricultural research center	62	77.8 (188.6)	26.0	40.0	9.9	1,490

Notes: Standard deviations are given in parentheses. Sample excludes two extreme outliers and includes only returns to research only and combined research and extension, so that the maximum sample size is 1,772. In some instances further observations were lost owing to incomplete information on the specific characteristics of interest.

[a]United States and Canada.

[b]Australia and New Zealand.

[c]Japan and Israel.

CHAPTER 7

Meta-Analysis of Returns to Research

The previous chapter compares studies of rates of return to research and summarizes results according to characteristics of the studies, generally one characteristic at a time; the comparisons are informal and qualitative. We now turn to the use of multivariate methods of analysis and more formal, more quantitative comparisons. This is meta-analysis.

In this chapter, we combine the theory and conjectures from Chapter 5 and the data described in Chapter 6 to obtain some more formal evidence of the roles of the various factors as determinants of the estimated returns to agricultural research. Here we ask formally both types of questions identified in Chapter 2: (1) Does factor X appear to influence the estimated rate of return to agricultural research, and is the effect statistically significant? (2) What is the magnitude of the effect of factor X on the estimated rate of return to agricultural research?

The multiple regression approach to meta-analysis is appropriate when the analyst hypothesizes that more than one factor plays a significant role in explaining the study outcome (Hedges and Olkin 1985). Ordinary least squares (OLS) multiple regression is a standard statistical technique. Under certain conditions OLS will give an unbiased and the most efficient (minimum variance) linear estimate of the magnitude of the influence of a particular explanatory factor on the rate of return to research (the factor's estimated coefficient). This technique will also provide an estimate of how much of the variation in the rate of return to research is explained by the set of explanatory factors included in the regression analysis (the R^2 measure, also called the coefficient of determination).

The Regression Models

General Form

Recall from Chapter 5 that we hypothesize the functional relationship between the rate of return measure and the factors affecting it as follows:

$$m = m^*(\mathbf{r}) + v(\mathbf{a}, \mathbf{r}, \mathbf{e}, u) = f(\mathbf{a}, \mathbf{r}, \mathbf{e}) + u,$$

Table 18—Summary of explanatory variables

Characteristics of the:	Details
Measure (m)	Real or nominal rate of return Marginal or average rate of return Private or social rate of return Ex ante or ex post rate of return Rate of return to research only, extension only, or both estimated Rate of return imputed from a benefit-cost ratio
Analyst (**a**)	First author's place of employment Self-evaluation or independent assessment
Research (**r**)	Government versus other research performers Commodity focus of research Research type (basic versus applied, public versus private, or both) Developed or developing country research performer Time period in which research benefits occur
Research evaluation (**e**)	Date of evaluation publication Single project versus program or institutionwide evaluation Evaluation published in a refereed journal or other outlet Supply shift estimated econometrically or not Form of research-induced supply shift (pivotal, parallel) Experimental industry data used to calculate supply shift Length of gestation lag Short (≤15 years) or long benefit lag assumed Adjustment for research spillovers Adjustment for market distortions

where m is the measured rate of return, m^* is the true rate of return, v is the measurement error, **a** is a vector of analyst characteristics, **r** is a vector of research characteristics, **e** is a vector of features of the evaluation of the research, and u is a random term.

The components of each of these categories are summarized in Table 18. It is from these that the empirical regression model is to be constructed. The regression equation is a linear model of the form

$$m = b_0 + \mathbf{X}\mathbf{b} + \varepsilon,$$

where b_0 is the intercept, $\mathbf{X}$ is the matrix of explanatory variables included in the model, $\mathbf{b}$ is the vector of slope coefficients, and ε is the error term.

Almost all the explanatory variables used in this study are dichotomous dummy (or indicator) variables coded as equal to one if some characteristic is present and equal to zero if it is not. Sometimes indicator variables are used to indicate the presence of one of a set of characteristics, such as several categories of researcher affiliations. The dummy variable for one of the categories, the default category, must be omitted from the regression in order to avoid the "dummy variable" trap, which occurs when too many dummy variables are included (in the typical case, when dummy variables are included for all categories, a linear combination of them yields a vector of ones, the same as the intercept variable, so that the model is overidentified, making the design matrix singular) and the coefficients cannot be estimated. The "default" category is represented by the intercept term of a linear model, and the dummy variables are used to measure the effects of other categories relative to the default.

As a practical matter we cannot include every explanatory variable we might wish to include in one large model. We would most assuredly run into multicollinearity problems if we tried. Extreme multicollinearity results in an inability to perform the regression at all. A lesser form of multicollinearity arises where two or more of the explanatory variables are highly correlated with each other, but not to the point of exact linear dependency. The result of this type of multicollinearity is that the estimated coefficients are unreliable and may vary from sample to sample (for example, Judge et al. 1982). When the precision of the estimates is low, we have less confidence in the estimates of the magnitudes of the effects of the variables on the rate of return measure.

Model Specification Issues

The foregoing discussion assumes a simple linear functional form to be applied to the data, to estimate a common set of parameters as being applicable to all the observations. Implicitly this means that the different explanatory variables are assumed to have independent, additive (and, for the dichotomous dummy variables, fixed) effects on the estimated rates of return. Hence, for instance, the effect of computing the rate of return in real versus nominal terms is assumed implicitly to be constant across all the observations (that is, the inflation effect on the rate of return is constant across all time periods, all locations, all types of research, and all rate of return estimation methods). One could question whether this assumption is indeed reasonable, as did one of our reviewers.

An alternative approach would be to allow for interaction effects among all combinations of the explanatory variables, so that each effect of interest would be allowed to differ among observations. If we were to allow for all such interaction effects, even with our rather large data set, we would have many more parameters to estimate than observations. At the extreme, if every observation had at least one characteristic different from every other, this approach would mean estimating a separate set of coefficients for each observation, which is clearly impossible. Indeed the whole idea of the meta-analysis is to pool observations across studies, and thereby to gain an enhanced understanding of the whole body of evidence by increasing the effective degrees of freedom. In order to gain precision, however, it is necessary to assume that some elements are constant across studies, and there is a potential risk of bias if we fail to fully control statistically for elements that vary across studies.

A practical solution is to allow for a small number of interaction effects, based on a priori evidence concerning which of those effects might be relatively important or interesting. In particular (and partly in response to the reviewer's concern) we allow for the interaction between the real-nominal distinction and two additional factors: (1) whether the rate of return applied to a developing country (where inflation effects might have been more important) and (2) whether the rate of return calculation included data from the 1970s (when inflation rates were generally higher than in other periods). We also allow for some interaction effects in the evaluation methods, namely (1) the use of an explicit surplus measure in interaction with the assumed form of the research-induced supply shift (parallel, pivotal, or other) and (2) the interaction between lag length and whether the rate of return was estimated econometrically (in which case a shorter lag would be expected to have a positive effect) or noneconometrically (a negative expected effect).

All other effects are treated in the analysis as constant across observations. To the extent that other effects are not constant across observations, the model is misspecified and the parameter estimates may be biased. On the other hand, in a model that already includes many explanatory variables, and the potential for multicollinearity problems, any attempt to avoid bias by increasing the number of explanatory variables and parameters to be estimated will surely mean less precise estimates. In consideration of these issues, we opted for a simpler, more parsimonious model, allowing for only a small number of interaction effects. Our estimation results, and our observation of the generally small signal-to-noise ratio in our data, tend to support these decisions.

Potential Problems with the Regression Errors

OLS regression methods provide the most precise (best), linear, unbiased estimates (BLUE) when the errors are independent of one another among observations and can be assumed to come from the same normal distribution with a mean of zero and a common variance, σ^2. When we cannot assume a common variance, the parameter estimates should still be unbiased, but they will not be the most precise (minimum variance) estimates that could be obtained. As a result the estimated standard errors of the coefficient estimates will probably be overstated, so that when we test the statistical significance of the coefficient associated with an explanatory variable the variable is more likely than it should be to be discarded as insignificant. This problem of different error variances across observations in a regression equation is called heteroskedasticity, and it is explained in any basic statistics text (see Neter and Wasserman 1974, for example).

It might also be true that some of the errors from the measures are not statistically independent, thus violating another assumption required for OLS methods to provide BLUE estimates. For example, some studies report different rates of return associated with different assumptions about the shape or the length of the research lag, but each measure is constructed using the same data set over the same time period and is measuring the rate of return to the same research expenditure. In addition, in some instances different studies use the same data set. Hence we might expect to find a common variance and some covariance among certain clusters of errors—such as those coming from the same study or studies using the same or similar data—but still expect these errors to be independent of and have a different variance from other errors or clusters of errors.

If both types of error problems (heteroskedasticity and statistical dependence among the errors) are suspected, it is difficult to tell what the overall effect might be on the estimated parameters and their standard errors. The standard solution to the first problem, heteroskedasticity, involves correcting the diagonal elements (the variances) in the covariance matrix to account for the clustered differences. This is the White covariance correction.[32] There is no tried and true way to correct for the clusters of nonzero off-diagonal elements (the covariances), although some have suggested random sampling with replacement from the smallest independent unit of observation (for example, a particular study or group of studies) a large number of times to estimate a covariance matrix that should exhibit less statistical dependence among the errors. This technique is called bootstrapping. There is no formal proof in the literature that bootstrapping fixes the problem in all cases, but intuitively it has some appeal (Hall 1984; Hall, Horowitz, and Jing 1995). In our case, however, since we have several possibly dependent groups (for example, within study, within authors, and within data series), it is not clear even how to establish the smallest independent unit.[33] Furthermore, it is not possible to tell what will be the effect on the estimated coefficients and their standard errors if the problem of lack of independence among the errors is corrected and the heteroskedasticity problem is not.

The potential distortions arising from heteroskedasticity or statistical dependence among the errors might be expected to be small when a data set is quite "large." In large samples, any small violations of the OLS assumptions may be assumed to be swamped by the "law of large numbers" and not to affect the precision or consistency of the estimates to any significant extent. Since our data set is relatively large, we appeal to this notion in our meta-analysis and do not correct the error covariance matrix for either problem.

Empirical Models and Estimation Results

Data for the Analysis

As already noted, in order to reduce the role of the extreme observations in masking the information content of the data, we discarded outliers using the method proposed by Belsey, Kuh, and Welsch (1980), in which a number of statistical tests are used to assess changes in the predicted and residual values as a consequence of deleting observations. In all, 30 observations were discarded as being outliers having undue influence on the regression parameters. In addition, 2 extreme observations had already been discarded as outliers, and a further 726 observations were dropped from the re-

[32] See Smith and Huang (1995) for another example of this problem.

[33] We thank Kerry Smith for pointing this out to us.

Table 19—Frequencies of various rate of return characteristics

Variable	Percentage of sample: All observations[a]	Percentage of sample: Regression sample[b]
Characteristics of the rate of return measure		
Real rate of return	71.7	75.9
Nominal rate of return	28.3	24.1
Ex ante evaluation	21.5	19.9
Ex post evaluation	78.5	80.1
Average rate of return	58.6	68.9
Marginal rate of return	41.4	31.1
Private rate of return	3.2	2.8
Social rate of return	96.8	97.2
Reported rate of return	95.0	94.2
Rate of return derived from benefit-cost ratio	5.0	5.8
Rate of return to research only	60.7	53.0
Rate of return to extension only	4.2	1.6
Rate of return to both research and extension	33.3	45.4
Characteristics of the analyst		
First author employer is:		
Government	17.5	19.4
University	68.2	61.3
An international research center	4.8	6.8
An international research funding body	2.2	2.9
A private organization	3.0	3.1
Unknown	4.0	6.0
Independent research evaluation	62.3	55.9
Self-evaluation	15.8	21.1
Unclear if self-evaluation or independent	21.9	23.0
Characteristics of the research		
Research performer is:[c]		
Government	70.2	70.9
University	32.3	25.0
An international research organization	3.3	4.9
Private sector	8.9	8.0
Other (international funding body or unknown)	15.2	17.9
Research applies to:		
All agriculture[d]	23.3	18.4
Tree crops	6.2	5.2
Field crops	52.3	55.1
Livestock	12.7	14.2
Natural resources (forestry and fisheries)	4.2	5.4
Unspecified research focus	1.3	1.7
Scope of R&D is not specified as basic	98.9	98.8
Scope of R&D is specified as basic	1.1	1.2
Public R&D	85.6	89.0
Private R&D	0.7	1.2
Both public and private R&D (or unspecified)	12.3	9.8

(continued)

Table 19—Continued

Variable	Percentage of sample: All observations[a]	Percentage of sample: Regression sample[b]
Developing country research performer	41.4	46.5
Developed country research performer	58.6	53.5
Characteristics of the research evaluation		
Evaluation of a:		
Single project	15.4	19.9
Research program	16.7	22.7
Research institution	8.8	7.0
Multiple research institutions	59.0	50.4
Nonjournal publication	66.9	62.5
Evaluation published in a refereed journal	33.1	37.5
Noneconometric study	48.6	57.6
Supply shift estimated econometrically	51.4	42.4
Benefits calculated using:		
Explicit surplus measures with a parallel supply shift	13.5	16.7
Explicit surplus measures with pivotal supply shift	20.0	23.4
Explicit surplus measures with neither pivotal nor parallel supply shift	0.8	1.2
Implicit surplus measures	26.4	27.6
Other	39.2	31.1
Supply shift estimated noneconometrically using industry data	65.8	61.6
Supply shift estimated noneconometrically using experimental data	34.2	38.4
Overall research lag is long (≥15 years)	61.4	57.7
Overall research lag is short (<15 years)	38.6	42.3
Econometrically estimated supply shift with a long research lag	72.5	72.1
Econometrically estimated supply shift with a short research lag	27.5	27.9
No allowance for spillovers	80.1	89.5
Spillins considered	14.9	10.5
Spillouts considered	2.7	0.2
Both spillins and spillouts considered	2.3	0.7
Distortions not considered[c]	83.0	79.7
Distortions from farm programs considered	7.1	9.8
Exchange rate distortions considered	4.4	4.7
Deadweight losses from taxation considered	2.9	2.2
Environmental impacts considered	0.7	1.0
Other distortions considered	3.1	4.5

[a] Sample includes 1,884 observations (that is, excludes two extreme outliers).
[b] Sample includes 1,128 observations.
[c] In this group some publications or estimates belong to combinations of categories such that more than one category was counted for a given observation. As a result the percentages may sum to more than 100 percent.
[d] Includes observations scored as either all agriculture or crops and livestock.

Table 20—Conditional mean rates of return for variables in regression data set

	Summary statistics				Summary statistics		
Default category	Number[a]	Mean	Standard deviation	Explanatory variable	Number[a]	Mean	Standard deviation
		(percentage)				(percentage)	
Real	856	63.64	87.14	Nominal	272	67.71	82.72
Ex ante	225	85.91	140.34	Ex post (or unknown)	903	59.32	65.00
Average	777	64.29	94.56	Marginal	351	65.35	63.52
Private	32	80.24	157.61	Social	1,096	64.17	83.16
Research only	598	79.62	107.83	Extension only	18	80.06	85.59
				Both research and extension	512	46.57	43.75
Reported	1,063	56.76	61.80	Imputed from a B-C ratio	65	193.22	221.92
First author affiliation—government	219	65.75	82.47	University	692	66.79	95.15
				International research center	77	61.74	55.41
				International funding body	33	60.24	68.49
				Private sector (or unknown)	35	67.68	42.03
Independent assessment	890	67.11	89.23	Self evaluation	238	55.31	72.44
Government (research performer)	800	57.09	59.76	University research performer	282	89.46	133.06
				International research organization	55	55.50	50.38
				Private sector	90	49.55	41.16
				Other	202	56.84	83.38
All agriculture	207	53.16	51.27	Tree crops	59	70.95	106.95
				Field crops	622	65.76	92.16
				Livestock	160	82.90	94.00
				Natural resources	61	40.96	71.35
				Unspecified research focus	19	55.08	46.12
Not specified as basic research	1,115	64.24	86.27	Specified as basic research	13	100.01	131.37
Public research	1,004	66.67	90.03	Private research	13	79.77	68.11
				Both private and public research	111	44.69	32.15

Developing-country performers	525	54.06	53.16	Developed-country performers	603	73.83	105.96
Single project evaluated	224	104.52	158.80	Research program evaluated	256	41.91	37.46
				Research institution evaluated	79	68.02	43.02
				Multiple research institutions evaluated	569	58.67	54.94
Evaluation published as a book or chapter, discussion paper, report, or other	705	59.29	68.20	Evaluation published as an article in a refereed journal	423	73.51	109.08
Noneconometrically estimated supply shift	650	65.92	101.75	Econometrically estimated supply shift	478	62.87	58.40
Benefits not calculated directly from an econometric model	788	65.26	93.67	Benefits calculated directly from an econometric model	340	63.25	65.28
Benefits calculated using an explicit surplus model with a parallel supply shift	188	52.02	74.97	Using an explicit surplus model with a pivotal supply shift	264	50.64	48.83
				Using an explicit surplus model with neither a pivotal nor a parallel supply shift	14	50.00	19.97
				Using an implicit surplus model	311	86.39	126.48
Industry data for supply shift	695	59.48	57.90	Experimental data for supply shift	433	72.89	117.60
No gestation lag	911	64.92	90.48	Gestation lag > 0	217	63.56	64.57
Long lag (≥15 years)	651	62.74	98.95	Short lag (<15 years)	477	69.21	64.50
Spillovers not considered	999	62.91	90.10	Spillins only	119	78.24	41.94
				Spillouts only	2	63.00	29.70
				Both spillins and spillouts	8	84.00	39.44
Distortions not considered	899	66.85	92.23	Farm program distortions	110	57.13	47.85
				Exchange rate distortions	53	46.17	50.19
				Deadweight losses from taxation	25	81.37	49.07
				Environmental impacts	11	120.62	137.91
				Other distortions considered	51	30.46	25.10
Overall average rate of return	*1,128*	*64.66*	*86.08*				

[a]Number of observations in the regression sample having particular attributes.

gression sample because of missing information. Table 19 shows the frequencies of the various rate of return characteristics for two sets of data: *All observations* refers to the original full sample of 1,886, less the 2 extreme outliers. *Regression sample* refers to the 1,128 used in the regression. The entries in the table are grouped so that the percentages of the regression sample sum to 100 within a group. For example, of the 1,128 *All observations* sample, 53.0 percent of the observations from the regression sample refer to rates of return to research only, 1.6 percent to extension only, and the remaining 45.4 percent to both research and extension. It can be seen that, in several categories, certain characteristics (for instance, private rates of return, privately performed research, research performed by international organizations, or research with a natural resources focus) are not highly represented in either sample.

Conditional mean rates of return associated with each variable, representing the mean rate of return among those observations for which the variable is present, are shown in Table 20. The overall average rate of return across all 1,128 observations used in the regression was 64.7 percent per year, with a standard deviation of 86.1 percent per year. The estimated annual rates of return averaged 80 percent for research only, 80 percent for extension only, and 47 percent for research and extension combined. The entries in the table speak for themselves, and some patterns are revealed, but these might be misleading. The purpose of the regression analysis is to account jointly for multiple influences on the estimated rates of return.

The regression model includes all the variables that economic theory and experience led us to believe to be important for explaining the variation in the rate of return, as well as some that are the subject of debate among research evaluators. Almost all are indicator variables, for which the estimated coefficient in the regression model represents the difference in the rate of return (in percentage points), relative to the default category, if that particular variable is a characteristic of the rate of return measure. For example, under *Characteristics of the research,* the default category of research focus is *All agriculture.* The estimated coefficients for each of the other categories in the group indicate the difference in the rate of return for that category relative to the default category. So we can say, for instance, that when the research evaluation pertains to *Natural resources (forestry and fisheries),* the rate of return measure is (on average) about 94.46 percentage points lower than when the evaluation pertains to *All agriculture.* Or when the evaluation applies to *Tree crops,* the rate of return measure is (on average) about 18.88 percentage points higher than when the evaluation pertains to *All agriculture.* And, comparing these two estimates, when the evaluation applies to *Tree crops,* the rate of return measure is (on average) 113.3 percentage points higher [18.88 – (–94.46)] than when the evaluation pertains to *Natural resources.* We can compare the rates for any two groups by taking the difference between their coefficients in this fashion.

Summary of Findings

The results of the regression analysis are reported in Table 21. The model accounts for about one-third of the total variation in the data, as indicated by the R^2 measure.

Table 21—Meta-analysis regression results

Default category	Explanatory variable included	Estimated coefficient	t statistic
	Intercept term	86.57	3.68***
	Characteristics of the rate of return measure		
Real	Nominal	–1.54	–0.10
All other observations	Nominal × developing country interaction	5.98	0.39
All other observations	Nominal × 1970s interaction	26.12	2.12**
Ex ante	Ex post	17.65	2.04**
Average	Marginal	7.20	0.78
Private	Social	14.32	0.91
Research only	Extension only	–57.70	–2.04**
	Both research and extension	–33.63	–5.76***
Reported	Imputed from benefit-cost ratio	162.67	12.13***
	Characteristics of the analyst		
First author affiliation—government	University	–15.05	–2.06**
	International research center	5.09	0.42
	International funding body	2.54	0.13
	Private sector	–60.94	–3.78**
	Unknown affiliation	–48.65	–4.07***
Independent assessment	Self-evaluation	–22.00	–2.65**
	Unclear if self-evaluation or not	2.96	0.43
	Characteristics of the research		
Government research performer	University research performer	2.46	0.35
	International research organization	–2.84	–0.22
	Private sector	18.13	1.16
	Other (international funder or unknown)	8.07	0.95
All agriculture	Tree crops	18.88	1.22
	Field crops	25.10	2.50**
	Livestock	12.09	1.07
	Natural resources (forestry and fisheries)	–94.46	–6.40***
	Unspecified research focus	7.73	0.65
Not specified as basic research	Specified as basic research	–34.52	–1.33
Public research	Private research	18.97	0.69
	Both private and public research	–4.10	–0.30
Developing country performer	Developing country performer	13.20	1.71*
Median year of benefits[a,b]		3.24×10^{-3}	0.51
Median year of benefits squared[a,b]		2.03×10^{-7}	0.11
	Characteristics of the research evaluation		
Publication date[a]		–0.84	–1.92*
Single project evaluation	Research program evaluated	–41.33	–4.53***
	Research institution evaluated	–68.91	–4.83***
	Multiple research institutions evaluated	–53.13	–4.91***

(continued)

Table 21—Continued

Default category	Explanatory variable included	Estimated coefficient	*t* statistic
Nonjournal publication	Evaluation published in a refereed journal	–15.58	–2.55**
Noneconometric study	Econometrically estimated supply shift	–18.53	–1.61
Benefits calculated directly from econometric model	Benefits imputed using:	10.09	1.33
	Explicit surplus measure with pivotal supply shift		
	Explicit surplus measure with neither pivotal nor parallel supply shift	–54.23	–2.38**
	Implicit surplus measure	17.66	2.20**
Industry yield data for supply shift	Experimental yield data for supply shift	10.46	1.37
Gestation lag length (years)[a]		–4.59	–7.47***
Long lag (≥15 years)	Short lag (≥15 years)	–11.62	–1.49
Long lag, econometrically estimated supply shift	Short lag, econometrically estimated supply shift	38.30	3.37***
Spillovers not considered	Spillins only	2.67	0.26
	Spillouts only	21.90	0.30
	Both spillins and spillouts	–34.50	–1.22
Distortions not considered	Farm program distortions	–5.00	–0.62
	Exchange rate distortions	–15.56	–1.24
	Deadweight losses from taxation	8.92	0.55
	Environmental impacts	39.98	1.30
	Other distortions considered	–9.31	–0.78
Model R^2		0.35	
Number of observations		1,128	

[a] These variables are entered in continuous, not dichotomous, form.
[b] Variable is median year of benefit stream minus 2000.
* Significant at the 90 percent confidence level; ** significant at the 95 percent confidence level; ***significant at the 99 percent confidence level.

Some of the variation among the estimates is attributable to factors not included in the model (such as details about particular crops, studies, projects being evaluated, and analysts) for which we could not afford to make specific allowance for the reasons previously outlined. More important than the total explanatory power of the model, for our present purposes, are the signs and magnitudes of particular coefficients in the model. A high proportion of the estimated coefficients in the model are of plausible magnitudes and of signs that can be rationalized. We now turn to a discussion of these.

Statistically Significant Effects on the Rate of Return

Recall that meta-analysis seeks to answer two types of questions: Is the effect of factor X on outcome Y statistically significant? If the effect is statistically significant, how important (large) is the effect? We use the standard 95 percent level of confidence as the threshold level for statistical significance. Those estimated coefficients not meeting this standard are assumed to be insignificant effects (they do not make a statistically discernible difference in the estimate of the rate of return). When a variable has a positive coefficient in the regression that is statistically significantly different from zero at the 5 percent level, we infer that larger values of that variable (or the presence of that characteristic for categorical variables) are associated with higher rates of return to research. Higher rates of return are indicated when the rate of return

- is nominal (versus real) and computed using data for the inflationary 1970s,
- is ex post (versus ex ante),
- applies to field crops (versus all agriculture),
- is based on an implicit surplus measure rather than econometric derivation, or
- is based on an econometrically estimated supply shift with a short (versus long) lag.

When a variable has a negative coefficient in the regression that is statistically significantly different from zero, we infer that larger values of that variable (or the presence of that characteristic for categorical variables) are associated with lower rates of return to research. *Lower* rates of return are indicated when

- the rate of return is for extension only (versus research only),
- both research and extension effects are included (relative to either alone),
- the analyst is employed by a university (versus government),
- the analyst is employed by the private sector (versus government),
- the analyst's employer is not known (versus government),
- the research evaluation is a self-evaluation (rather than an independent evaluation),
- the research is on natural resource issues, rather than agricultural or other topics,
- the research scope is for a program (versus a single project),
- the research scope is for one or more institutions (versus a single project),
- the evaluation is published in a refereed journal compared with less formal outlets,
- explicit surplus is measured without using either a pivotal or a parallel supply shift, or
- a longer gestation lag is used.

Key Effects on the Rate of Return

Now we review the findings in more detail, considering the key results in turn, beginning from the top of the table and working down through the characteristics of the *measure* (*m*) of the rate of return to research, the *analyst* (**a**) who wrote the study, the *research* (**r**) being evaluated, and the *evaluation* (**e**) methodology.

Characteristics of the Rate of Return Measure. Nominal rates of return should tend to be higher than real rates of return (the difference reflecting, approximately, the general rate of inflation for the same geographical location and period of analysis). This relationship is evident only in the subset of studies for which the benefit stream includes the inflationary 1970s, in which case nominal rates of return were on average 25 percentage points (26.12 – 1.54 percent) higher than their real counterparts, and this effect is statistically significant at the 5 percent level. The rate of return in ex post analyses was higher than that in ex ante analyses by 18 percentage points, which is consistent with our conjecture that ex post analyses tended to pick "winners." Properly measured, social rates of return to research should be greater than private rates, because social rates take into account positive spillovers. The regression indicates that the social rates of return are indeed higher, by about 14 percentage points, but this coefficient is not statistically significantly different from zero.

Compared with measures of rates of return to research only, the results suggest that measures of the rate of return to extension only or to both research and extension were lower (by 58 and 34 percentage points, respectively). These effects are statistically significant. The cost of extension effort is not accounted for in the research-only measures, whereas extension effects are difficult to exclude from the benefits stream, and this would result in an upward bias in the research-only measures compared with measures of either extension alone or research and extension combined. In contrast, the conditional means suggest that the rates of return to research only and extension only were about equal, and both were much higher than for research and extension combined.

Finally we imputed some 65 rate of return estimates from reported estimates of benefit-cost ratios, and the regression results indicate that these imputed rates of return were 163 percent per year higher than reported rates of return, other things equal. This might have resulted from our assumption of an infinite stream of constant benefits for the imputed rates of return, while the directly reported rate of return measures contain a mixture of assumptions about lag lengths and the flows of benefits over time. In addition, however, it might be because absurdly high benefit-cost ratios are not as obvious as the absurdly high rates of return they imply, so that less effort might have been spent attempting to reduce the returns in studies that reported benefit-cost ratios instead of rates of return.

Characteristics of the Analyst. Several aspects of the affiliation of the research evaluator had statistically significant effects on the rate of return measure. Most evaluations are carried out by government employees (Table 6). When the evaluation was instead performed by an analyst employed in a university or the private sector, or the employer was unknown, the rate of return was statistically significantly lower (by 15, 61, or 49 percent per year, respectively).

Self-evaluations—a more direct measure of any tendency to bias estimates—provide significantly lower rate of return estimates (by 22 percent per year). At first blush, it may seem surprising to find that self-evaluations yield rates of return that are lower than more independent studies. Perhaps self-evaluators are simply better informed, have access to better data, and are less biased as a result. As can be seen in the quote from McMillen (1929) that opened Chapter 1, another explanation is that self-evaluators want to be considered plausible and are inclined to bias their estimates downward (for many find typical estimates too high to be really plausible) for that reason.[34]

Characteristics of the Research. The returns to research do not seem to depend on who does the research. The default category of research performer is government; there are no statistically significant effects, and the point estimates are generally small for other categories of research performer. There is also no measurable difference in estimated rates of return between privately and publicly performed research.

Research focus matters. The estimated coefficients on the variables representing the *research focus* suggest that compared with all agriculture, the rates of return were 25 percent per year higher for research on field crops and 95 percent per year lower for research on natural resources. It should be noted that only 61 studies fell into this category, mostly concerning forestry and some fisheries research, and that these might not be representative of the broad subject matter of natural resources research, much of which has not been the subject of evaluation studies.

There is no significant difference in rates of return related to whether studies reported basic or other categories of research, nor between research that was identified by authors as private in nature versus public in nature. Where the research was conducted may matter. The point estimates indicate that if the research took place in a developed country, the rate of return was higher by 13 percent per year (perhaps because of better research infrastructure or better research training), but this effect was only statistically significant at the 10 percent level.

Some suggest that the rate of return to agricultural R&D ought to be expected to decline over time, owing to some loose notion of diminishing returns or the view that the easy problems have already been solved—nature is increasingly niggardly. On the other hand, others have said that new information and biotechnologies offer the potential for an unprecedented technological revolution. Both the linear and quadratic time trend terms were statistically insignificant. Hence there is no evidence that the rate of return to agricultural R&D has declined over time (in fact the point estimates of both coefficients were positive).

Characteristics of the Research Evaluation. The impact of progress in research evaluation methodology on the measured rate of return can be proxied by the publication date of the evaluation. The coefficient on publication date indicates a significant downward trend of about 1 percent per year each year over the postwar period, but this was only significant at the 10 percent level.

The remaining results confirm some of our predictions concerning the implications of certain modeling assumptions. First, as anticipated, more aggregative studies generally mean lower rates of return. The coefficients are significant and nega-

[34] More generally we might expect to find a bias toward the conventional wisdom, with "low" estimates being biased upward and "high" estimates being biased downward.

tive for evaluations of entire programs of research, institutionwide research, and research by multi-institutional agencies. These results suggest that rates of return are about 40–70 percent per year lower for evaluations of more aggregated research investments relative to single-project evaluations—probably a reflection of selection bias in the less aggregative studies (that is, those evaluating only impressive projects or programs or parts thereof).

A published result may be expected to have been more heavily scrutinized, and this might lead to lower rates of return. This hypothesis is supported in our regression. The rate of return measure is estimated to be 16 percent per year lower when the results were reported in a refereed journal than when they appeared in the default category of "gray" literature.

The next block of variables refers to the approach used to compute benefits. First, there was no statistically significant difference in the estimated rate of return between econometric and noneconometric studies, but the point estimate suggests that when the supply shift was estimated econometrically, the rate of return was lower. Assumptions about the form of the research-induced supply shift had some effect in studies using explicit or implicit surplus measures. The default category is a parallel shift. Everything else equal, a pivotal supply shift is known to result in smaller estimates of research benefits than a parallel one, so it is surprising that this was not reflected in a lower rate of return in studies using a pivotal supply shift. However, rates of return were significantly lower, by 54 percent per year, in the very small number of estimates (14) that used neither parallel nor pivotal shifts. The use of an implicit surplus model (GARB = kPQ) rather than an explicit model to compute benefits implied an 18 percent per year higher rate of return, a statistically significant difference. The use of experimental yields to measure the supply shift versus the default (industry yields) did not affect the rate of return.

Several key assumptions about the lag structure were found to have significant implications for the reported rate of return. First, a longer gestation lag meant a lower rate of return (by 4.6 percent per year for each additional year of gestation). Second, overall lag length matters. Studies that assumed short lags (≤15 years) for research benefits found rates of return similar to those that used longer lags, although the point estimate suggests that truncation of the lag reduces the rate of return. This effect would be expected in a noneconometric study in which truncation of the lags means the omission of some benefits. However, Alston, Craig, and Pardey (1998) showed that in econometric studies of returns to research the arbitrary truncation of the lag distribution for the stream of net benefits could lead to serious upward biases in the estimated rate of return. As they predicted, *econometric* studies that used short lags found rates of return that were 38 percent per year *higher* than those that used longer lags. This statistically significant coefficient reflects the result that, because of the omitted variables problem discussed earlier, truncation of lags in the stream of net benefits from research biases the rate of return upward. It is noteworthy that the regression analysis picked up both the positive and negative biases from truncation of lags.

The remaining sets of coefficients that relate to the effects of allowing for *research spillovers* and allowing for *distortions* are all statistically insignificant and mostly small. In many of these instances theory does not give any clear-cut indication of the likely sign of the effect, but in three instances the signs of coefficients were unexpected: those referring to studies that took account of exchange rate distortions, the deadweight losses from taxation, or environmental impacts. In each of these instances, the anomalous sign could easily have been the result of a small-sample problem or selection bias (in Table 20 these categories included only 53, 25, and 11 observations, respectively).

CHAPTER 8

Conclusion

This study has compiled a comprehensive data set of studies representing the entire postwar history of quantitative assessment of rates of return to agricultural research. Compared with previous, narrative reviews, this database is much more comprehensive. The consequences for drawing conclusions from this literature are both good and bad. The range of rates of return is large, which makes it harder to discern meaningful patterns in the rates of return and to identify those factors that account for the systematic variation in the evidence. But these are the data, and it is better to use objective and systematic methods to filter the results rather than ad hoc sample selection, which may entail corresponding bias.

To make our assessment of the evidence more meaningful, we excluded 30 observations that were statistically determined to be outliers exerting significant influence on the regression results, 2 extreme outliers, and a further 726 observations were lost because they did not include full information on all the explanatory variables in the model. This left 1,128 observations to analyze. Even so, it was difficult confidently to draw meaningful inferences from the tabulations and simple pairwise comparisons. It may be important to control for some of the systematic sources of variation in order to isolate a particular effect, especially given the importance of within-group variability.

For the most part there is a close connection between our key results from the multivariate analysis and our prior beliefs based on theory. Some issues, however, are strictly empirical, and these were a significant motivation for the study. Five questions were stated in the introduction, and we have been able to answer some of them clearly; others remain the subject of further analysis:

1. There is no evidence to support the view that the rate of return to research has declined over time.
2. The rate of return to research may be higher when the research is conducted in more developed countries.
3. The rate of return to research varies according to problematic focus, in ways that make intuitive sense. In general we would expect to see longer production cycles associated with lower rates of return, and the regression results indicate a significantly lower rate of return to natural resource management

research (primarily forestry) compared with the other categories, and a higher rate of return to research into (typically annual) crops.

4. A lower rate of return is found in studies that combine research and extension compared with studies evaluating only research.
5. Characteristics of the research evaluation itself—particularly the scope of the research being evaluated and choices about lags—were found to have important, systematic effects on the estimated rates of return, and most of these effects are reasonable.

In addition to these primary questions, we considered other possible systematic aspects of rate of return estimates that might reflect characteristics of the true rates of return or sources of bias in the estimates. For instance, characteristics of the measures themselves and of the analyst conducting the evaluation affected the rate of return measure in ways that were expected, and self-evaluations yielded significantly lower rates of return. On the other hand we were unable to detect any effect of accounting for spillovers or market distortions on measured rates of return to research.

Our purpose in conducting this study was to determine the information content of the rate of return evidence. One key finding is that there is much noise relative to signal (contrary to the conclusions of previous reviews, which stressed the central tendencies, concealing the noisy nature of the evidence). The study is useful in suggesting (and justifying) a degree of skepticism about the conventional wisdom and much of the specific evidence. Beyond this, we believe we have developed certain insights about the sources of variation in the measured rates of return, and certain of our conjectures about bias were borne out in our analysis. Our findings should be useful to policymakers who wish to use evidence on rates of return effectively in making R&D investment decisions.

References

Adusei, E. O., and G. W. Norton. 1990. The magnitude of agricultural maintenance research in the USA. *Journal of Production Agriculture* 3 (1): 1–6.

Alston, J. M., J. R. Anderson, and P. G. Pardey. 1995. Perceived productivity, forgone future farm fruitfulness, and rural research resource rationalization. In *Agricultural competitiveness: Market forces and policy choice. Proceedings of the 22nd International Conference of Agricultural Economists,* ed. G. H. Peters and D. D. Hedley. Aldershot, U.K.: Dartmouth.

Alston, J. M., B. J. Craig, and P. G. Pardey. 1998. Dynamics in the creation and depreciation of knowledge, and the returns to research. EPTD Discussion Paper No. 35. International Food Policy Research Institute, Washington, D.C. (revised 1999).

Alston, J. M., G.W. Edwards, and J. W. Freebairn. 1988. Market distortions and the benefits from research. *American Journal of Agricultural Economics* 70 (2) (May): 281–288.

Alston, J. M., G. W. Norton, and P. G. Pardey. 1995. *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Ithaca, N.Y., U.S.A.: Cornell University Press. Reprinted in 1998, Wallingford, U.K.: CAB International.

Alston, J. M., and P. G. Pardey. 1995. Research evaluation requirements in the CGIAR. International Food Policy Research Institute, Washington, D.C. Photocopy.

———. 1996. *Making science pay: The economics of agricultural R&D policy.* Washington, D.C.: American Enterprise Institute Press.

———. 1999. Principles for agricultural R&D policy. In *Paying for agricultural productivity,* ed. J. M. Alston, P. G. Pardey, and V. H. Smith. Baltimore, Md., U.S.A.: Johns Hopkins University Press.

Alston, J. M., P. G. Pardey, and H. O. Carter. 1994. *Valuing California's agricultural research and extension.* Agricultural Issues Center Publication No. VR-1. Davis: University of California.

Alston, J. M., P. G. Pardey, and J. Roseboom. 1998. Financing agricultural research: International investment patterns and policy perspectives. *World Development* 26 (6): 1057–1071.

Alston, J. M., P. G. Pardey, and V. H. Smith, eds. 1999. *Paying for agricultural productivity.* Baltimore, Md., U.S.A.: Johns Hopkins University Press.

Alston, J. M, R. J. Sexton, and M. Zhang. 1997. The effects of imperfect competition on the size and distribution of research benefits. *American Journal of Agricultural Economics* 79 (4): 1252–1265.

———. 1999. Imperfect competition, functional forms, and the size and distribution of research benefits. *Agricultural Economics* 21: 155–172.

Alston, J. M., and R. J. Venner. 2000. The effects of the U.S. Plant Variety Protection Act on wheat genetic improvement. EPTD Discussion Paper No. 62. International Food Policy Research Institute, Washington, D.C.

Arrow, K. 1962. Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity,* ed. R. R. Nelson. Princeton, N.J., U.S.A.: Princeton University Press.

Ballard, C. L., and D. Fullerton. 1992. Distortionary taxes and the provision of public goods. *Journal of Economic Perspectives* 6 (Summer): 117–131.

Belsey, D. A., E. Kuh, and R. E. Welsh. 1980. *Regression diagnostics.* New York: John Wiley.

Boyle, K. J., G. L. Poe, and J. C. Bergstrom. 1994. What do we know about ground water values? Preliminary implications from a meta analysis of contingent-valuation studies. *American Journal of Agricultural Economics* 76: 1055–1061.

Christian, J. E., and P. G. Pardey. 1999. The production and diffusion of policy knowledge: A bibliometric evaluation of the International Food Policy Research

Institute. International Food Policy Research Institute, Washington, D.C. Photocopy.

Cook, T. D., H. Cooper, D. S. Cordray, H. Hartmann, L. V. Hedges, R. J. Light, T. A. Louis, and F. Mosteller. 1992. *Meta-analysis for explanation: A casebook.* New York: Russell Sage Foundation.

Echeverría, R. G. 1990. Assessing the impact of agricultural research. In *Methods for diagnosing research system constraints and assessing the impact of agricultural research.* Vol. 2, *Assessing the impact of agricultural research,* ed. R. G. Echeverría. The Hague: International Service for National Agricultural Research.

Evenson, R. E., P. E. Waggoner, and V. W. Ruttan. 1979. Economic benefits from research: An example from agriculture. *Science* 205 (14 September): 1101–1107.

Farley, J. U., and D. R. Lehmann. 1986. *Meta-analysis in marketing.* Lexington, Mass., U.S.A.: Lexington.

Feldman, K. A. 1971. Using the work of others: Some observations on reviewing and integrating. *Sociology of Education* 44: 86–102.

Fox, G. C. 1985. Is the United States really underinvesting in agricultural research? *American Journal of Agricultural Economics* 67 (4): 806–812.

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee, with contributions from J. Fisher and S. Payson. 1996. Agricultural research and development: Public and private investments under alternative markets and institutions. USDA-ERS-NRED Agricultural Economic Report 735. Washington D.C.: United States Department of Agriculture.

Fullerton, D. 1991. Reconciling recent estimates of the marginal welfare cost of taxation. *American Economic Review* 81: 302–308.

Griliches, Z. 1957. Hybrid corn: An exploration in the economics of technological change. *Econometrica* 25 (4): 501–522.

———. 1958. Research costs and social returns: Hybrid corn and related innovations. *Journal of Political Economy* 66 (5): 419–431.

———. 1980. Hybrid corn revisited: A reply. *Econometrica* 48 (6): 1463–1465.

Hall, P. 1984. Resampling a coverage pattern. *Stochastic Processes and Their Applications* 20: 231–246.

Hall, P., J. L. Horowitz, and B.-Y. Jing. 1995. On blocking rules for the bootstrap with dependent data. *Biometrika* 82: 561–574.

Harris, M., and A. G. Lloyd. 1991. The returns to agricultural research and the underinvestment hypothesis—A survey. *Australian Economic Review* 95 (July–September): 16–27.

Hedges, L. V., and I. Olkin. 1985. *Statistical methods for meta-analysis.* New York: Academic Press.

Heim, M. N., and L. L. Blakeslee. 1986. Biological adaptation and research impacts on wheat yields in Washington. Paper presented at the annual meetings of the American Agricultural Economics Association, 1–4 August, Reno, Nevada.

Heston, A., R. Summers, D. A. Nuxoll, and B. Aten. 1995. The Penn world tables (mark 5.6). Center for International Comparisons. University of Pennsylvania, Philadelphia, January (computer files).

Horton, D., P. Ballantyne, W. Peterson, B. Uribe, D. Gapasin, and K. Sheridan, eds. 1993. *Monitoring and evaluating agricultural research.* Wallingford, U.K.: CAB International.

Huffman, W. E., and R. E. Evenson. 1993. *Science for agriculture: A long-term perspective.* Ames, Ia., U.S.A.: Iowa State University Press.

Judge, G. G., R. C. Hill, W. Griffiths, H. Lutkepohl, and T.-C. Lee. 1982. *Introduction to the theory and practice of econometrics.* New York: John Wiley.

Kealey, T. 1996. *The economic laws of scientific research.* Houndmills, U.K.: Macmillan.

Light, R. J., and D. B. Pillemer. 1984. *Summing up: The science of reviewing research.* Cambridge, Mass., U.S.A.: Harvard University Press.

Lindert, P. 1996. Soil degradation and agricultural change in two developing countries. Conference proceedings for the Conference on Global Agricultural Science Policy for the 21st Century, 26–28 September, Melbourne, Australia. 263–331.

Lindner, R. K., and F. G. Jarrett. 1978. Supply shifts and the size of research benefits. *American Journal of Agricultural Economics* 60 (1) (February): 48–58.

Lipsey, M. A. 1992. Juvenile delinquency treatment: A meta-analytic inquiry into the variability of effects. In *Meta-analysis for explanation,* ed. T. D. Cook, H.

Cooper, D. S. Cordray, H. Hartmann, L. V. Hedges, R. J. Light, T. A. Louis, and F. Mosteller. New York: Russell Sage Foundation.

Mann, C. 1996. Meta-analysis in the breech. *Science* 249 (3 August): 476–480.

Marra, M. C., and B. Schurle. 1994. Wheat yield risk and aggregation: A meta-analysis approach. *Journal of Agricultural and Resource Economics* 19 (1): 69–77.

Martin, W., and J. M. Alston. 1994. A dual approach to evaluating research benefits in the presence of policy distortions. *American Journal of Agricultural Economics* 76 (1) (February): 26–35

———. 1997. Producer surplus without apology: evaluating investments in R&D. *The Economic Record* 73 (221): 146–158.

McMillen, W. 1929. *Too many farmers: The story of what is here and ahead in agriculture.* New York: William Morrow.

Milchunas, D. G., and W. K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Environments* 63 (4): 327–366.

Moschini, G. C., and H. Lapan. 1997. Intellectual property rights and the welfare effects of agricultural R&D. *American Journal of Agricultural Economics* 79 (4): 1229–1242.

Nelson, R. R. 1959. The simple economics of basic scientific research. *Journal of Political Economy* 67: 297–306.

Neter, J., and W. Wasserman. 1974. *Applied linear statistical models.* Homewood, Ill., U.S.A.: Richard D. Irwin.

Norton, G. W., and J. S. Davis. 1981. Evaluating returns to agricultural research: A review. *American Journal of Agricultural Economics* 63 (4): 683–699.

Pardey, P. G., J. M. Alston, J. E. Christian, and S. Fan. 1996. *Hidden harvest: U.S. benefits from international research aid.* Food Policy Report. Washington, D.C.: International Food Policy Research Institute.

Pardey, P. G., J. Roseboom, and J. R. Anderson. 1991. *Agricultural research policy: International quantitative perspectives.* Cambridge, Mass., U.S.A.: Cambridge University Press.

Pardey, P. G., J. Roseboom, and N. M. Beintema. 1997. Investments in African agricultural research. *World Development* 25 (3): 409–423.

Pardey, P. G., J. Roseboom, and B. J. Craig. 1999. Agricultural R&D investments and impact. In *Paying for agricultural productivity,* ed. J. M. Alston, P. G. Pardey, and V. H. Smith. Baltimore, Md., U.S.A.: Johns Hopkins University Press.

Pardey, P. G., J. Roseboom, and S. Fan. 1998. Trends in financing Asian and Australian agricultural research." In *Financing agricultural research: A sourcebook,* ed. S. R. Tabor, W. Jansen, and H. Bruneau. The Hague, the Netherlands: International Service for National Agricultural Research.

Pasour, E. C., Jr., and M. A. Johnson. 1982. Bureaucratic productivity: The case of agricultural research revisited. *Public Choice* 39 (2): 301–317.

Robison, L. J., and P. J. Barry. 1996. *Present value models and investment analysis.* Northport, Ala., U.S.A.: Academic Page.

Schultz, T. W. 1953. *The economic organization of agriculture.* New York: McGraw-Hill.

Sexton, R. J., and Huang, S.-Y. 1996. Measuring returns to an innovation in an imperfectly competitive market: Application to mechanical harvesting of processing tomatoes in Taiwan. *American Journal of Agricultural Economics* 78 (3) (August): 558–571.

Smith, V. K., and J.-C. Huang. 1995. Can markets value air quality? A meta-analysis of hedonic property value models. *Journal of Political Economy* 103 (11): 209–227.

Smith, V. K., and Y. Kaoru. 1990. Signals or noise: Explaining the variation in recreation benefit estimates. *American Journal of Agricultural Economics* 72: 419–433.

Smith, V. K., and L. Osborne. 1993. Do contingent valuation estimates pass a scope test?: A preliminary meta analysis. Selected paper, joint meetings of the American Economic Association and the Association of Environmental and Resource Economists, 28 December, Boston, Mass.

Taveggia, T. C. 1974. Resolving research controversy through empirical cumulation: Toward reliable sociological knowledge. *Sociological Methods and Research* 2: 395–407.

U.S. Department of Health and Human Services. 1997. Description of evidence-based practice initiative. <http:/www.ahcpr.gov:80/guide/evidence.htm>.

Venner, R. J. 1997. An economic analysis of the U.S. Plant Variety Protection Act: The case of wheat. Ph.D. diss., University of California, Davis.

Wohlgenant, M. K. 1997. The nature of the research-induced supply shift. *Australian Journal of Agricultural Economics* 41 (3): 385–400.

World Bank. 1995. *World tables,* diskette version. Washington, D.C.

APPENDIX

Characteristics of the Meta-Data Set

Appendix—Characteristics of the meta–data set

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
*1958	Griliches Z.	Government/University	United States	All United States	Maize
*1958	Griliches Z.	Government/University	United States	All United States	Sorghum
*1963	Tang A.	Government	Other developed countries	Japan	All agriculture
1967	Peterson W.	Government/Private	United States	All United States	Poultry
1967	Peterson W.	Government/Private	United States	All United States	Poultry
1967	Peterson W.	Government/Private	United States	All United States	Poultry
*1968	Evenson R.	Government/University	United States	All United States	All agriculture
*1968	Evenson R.	Government/University	United States	U.S. state	All agriculture
1968	Fishelson G.	University	United States	All United States	All agriculture
1968	Fishelson G.	University	United States	All United States	All agriculture
*1969	Peterson W.	Government/University	United States	All United States	All agriculture
*1969	Peterson W.	Government/University	United States	All United States	All agriculture
*1970	Ayer H.	Government	Latin America/Caribbean	Brazil	Other crops
*1970	Ayer H.	Government	Latin America/Caribbean	Brazil	Other crops
1970	Schmitz A.	Private	United States	All United States	Other crops
*1971	Barletta N.	Government	Latin America/Caribbean	Mexico	Maize
*1971	Barletta N.	Government	Latin America/Caribbean	Mexico	Other crops
*1971	Barletta N.	Government	Latin America/Caribbean	Mexico	Other crops
*1971	Barletta N.	Government	Latin America/Caribbean	Mexico	Potato
*1971	Barletta N.	Government	Latin America/Caribbean	Mexico	Wheat
*1972	Ayer H.	Government	Latin America/Caribbean	Brazil	Other crops
*1972	Ayer H.	Government	Latin America/Caribbean	Brazil	Other crops
*1972	Duncan R.	Government	Australia	Australia	Pasture
*1972	Duncan R.	Government	Australia	Australia	Pasture
*1972	Himes J.	Government/University	Latin America/Caribbean	Peru	Maize
*1973	Evenson R.	Government	Asia/Pacific	India	All agriculture
*1973	Evenson R.	Government	Asia/Pacific	India	All agriculture
*1973	Patrick G.	Government	Latin America/Caribbean	Brazil	Unspecified
*1973	Patrick G.	Government	Latin America/Caribbean	Brazil	Unspecified
*1974	Huffman W.	Government	United States	U.S. state	Maize
*1975	Akino M.	Government	Other developed countries	Japan	Rice
*1975	Cline P.	Government/University	United States	All United States	All agriculture
1975	Evenson	Government	Africa	South Africa	sugarcane
1975	Evenson	Government	Asia/Pacific	India	sugarcane
1975	Evenson	Government	Australia	Australia	sugarcane
1975	Evenson	University	Asia/Pacific	India	All agriculture
1975	Evenson	University	Asia/Pacific	India	All agriculture
1975	Evenson	University	Global	Global	Maize
1975	Evenson	University	Global	Global	Wheat
1975	Evenson	University	Multiple locations	Developed	All agriculture
1975	Evenson	University	Multiple locations	Developing	All agriculture
1975	Mohan R.	Government	Asia/Pacific	India	All agriculture
*1976	Bredahl M.	University	United States	All United States	All livestock
*1976	Bredahl M.	University	United States	All United States	Dairy
*1976	Bredahl M.	University	United States	All United States	Other crops
*1976	Bredahl M.	University	United States	All United States	Poultry

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Implicit	Real	Average	Social	1	37.10	37.10
Research	Implicit	Real	Average	Social	1	19.75	19.75
Both	Direct	Nominal	Marginal	Social	1	35.00	35.00
Both	Direct	Real	Marginal	Social	1	33.00	33.00
Both	Explicit	Real	Average	Social	2	14.00	18.00
Research	Explicit	Real	Average	Social	2	17.00	21.00
Both	Direct	Real	Marginal	Social	1	112.00	112.00
Both	Direct	Real	Marginal	Social	10	30.00	180.00
Extension	Direct	Real	Marginal	Social	4	49.00	636.00
Research	Direct	Real	Marginal	Social	4	4.50	43.10
Both	Implicit	Real	Average	Social	1	19.00	19.00
Both	Implicit	Real	Marginal	Social	3	42.00	81.00
Research	Explicit	Real	Average	Social	3	87.00	95.00
Research	Implicit	Real	Average	Social	1	113.00	113.00
Both	Implicit	Nominal	Average	Social	2	55.74	76.92
Research	Explicit	Real	Average	Social	4	26.00	59.00
Both	Explicit	Real	Average	Social	3	54.00	79.00
Research	Explicit	Real	Average	Social	12	54.00	82.00
Research	Explicit	Real	Average	Social	1	69.00	69.00
Research	Explicit	Real	Average	Social	4	74.00	104.00
Research	Explicit	Nominal	Average	Social	3	80.00	89.00
Research	Implicit	Nominal	Average	Social	1	107.00	107.00
Both	Explicit	Real	Average	Social	2	58.00	68.00
Research	Explicit	Real	Average	Social	9	22.00	86.00
Both	Implicit	Real	Average	Social	4	39.30	65.50
Extension	Direct	Real	Marginal	Social	1	14.00	14.00
Research	Direct	Real	Marginal	Social	3	31.20	38.80
Extension	Direct	Real	Average	Private	5	13.00	155.00
Extension	Direct	Real	Average	Social	5	2.10	135.00
Extension	Direct	Nominal	Marginal	Social	1	1.30	1.30
Research	Explicit	Real	Average	Social	4	25.00	75.00
Both	Direct	Real	Marginal	Social	6	22.00	30.50
Research	Implicit	Real	Marginal	Social	2	29.00	40.00
Research	Implicit	Real	Marginal	Social	2	32.00	60.00
Research	Implicit	Real	Marginal	Social	2	50.00	60.00
Extension	Implicit	Real	Marginal	Social	1	17.00	17.00
Research	Implicit	Real	Marginal	Social	3	46.00	48.00
Research	Implicit	Real	Marginal	Social	6	9.00	50.00
Research	Implicit	Real	Marginal	Social	6	19.00	38.00
Research	Implicit	Real	Marginal	Social	2	21.00	60.00
Research	Implicit	Real	Marginal	Social	2	36.00	42.00
Extension	Direct	Real	Average	Social	1	15.00	15.00
Research	Direct	Real	Marginal	Social	1	46.00	46.00
Research	Direct	Real	Marginal	Social	1	37.00	37.00
Research	Direct	Real	Marginal	Social	1	36.00	36.00
Research	Direct	Real	Marginal	Social	1	43.00	43.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
*1976	Cline P.	Government/University	United States	U.S. state	All agriculture
*1977	Easter K.	University	United States	U.S. state	Maize
*1977	Easter K.	University	United States	U.S. state	Other crops
*1977	Hertford R.	Government	Latin America/Caribbean	Colombia	Other crops
*1977	Hertford R.	Government	Latin America/Caribbean	Colombia	Other crops
*1977	Hertford R.	Government	Latin America/Caribbean	Colombia	Rice
*1977	Hertford R.	Government	Latin America/Caribbean	Colombia	Wheat
*1977	Kahlon A.	Government	Asia/Pacific	India	All agriculture
*1977	Pee T.	Government/Private	Asia/Pacific	Malaysia	Other tree
*1977	Pee T.	Government/Private	Asia/Pacific	Malaysia	Other tree
*1977	Peterson W.	Government/University	United States	All United States	All agriculture
*1977	Wennergren E.	Government/University	Multiple locations	United States, Latin America/Caribbean	Crops and livestock
*1977	Wennergren E.	Government/University	Multiple locations	United States, Latin America/Caribbean	Sheep, goats
*1977	Wennergren E.	Government/University	Multiple locations	United States, Latin America/Caribbean	Wheat
*1978	Abidogun A.	Government	Africa	Nigeria	Other tree
1978	Araji A.	Government/University	United States	U.S. state	Fruit, nut
1978	Araji A.	Government/University	United States	U.S. state	Fruit, nut
1978	Araji A.	Government/University	United States	U.S. state	Other crops
1978	Araji A.	Government/University	United States	U.S. state	Other crops
1978	Araji A.	Government/University	United States	U.S. state	Potato
1978	Araji A.	Government/University	United States	U.S. state	Potato
1978	Araji A.	Government/University	United States	U.S. state	Rice
1978	Araji A.	Government/University	United States	U.S. state	Rice
1978	Araji A.	Government/University	United States	U.S. state	Sheep, goats
1978	Araji A.	Government/University	United States	U.S. state	Sheep, goats
*1978a	Evenson R.	Government	Multiple Locations	Africa, Asia, Latin America/Caribbean	Rice
1978b	Evenson R.	Government	United States	All United States	All crops
*1978a	Evenson R.	International	Asia/Pacific	Philippines	Rice
*1978a	Evenson R.	International	Asia/Pacific	Philippines	Rice
*1978a	Evenson R.	Government/International	Global	Global	Rice
*1978a	Evenson R.	Government/International	Global	Global	Rice
*1978	Flores-Moya P.	Government/International	Asia/Pacific	Philippines	Rice
*1978	Flores-Moya P.	Government/International	Asia/Pacific	Philippines	Rice
*1978	Fonseca M.	Government	Latin America/Caribbean	Brazil	Other tree
*1978	Fonseca M.	Government	Latin America/Caribbean	Brazil	Other tree
1978	Kislev Y.	Government	Other developed countries	Israel	Wheat
*1978	Lu Y.	Government/University	United States	All United States	All agriculture
*1978	Nagy J.	Government	Canada	Canada	Other crops
*1978	Nagy J.	Government	Canada	Canada	Other crops
*1978	Pray C.	Government	Asia/Pacific	Pakistan	Other crops
*1978	Pray C.	Government	Asia/Pacific	Pakistan	Other crops
*1978	Scobie G.	Government/International	Latin America/Caribbean	Colombia	Rice

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Both	Direct	Real	Marginal	Social	20	14.30	54.00
Research	Implicit	Real	Average	Social	16	320.00	1,720.00
Research	Implicit	Real	Average	Social	16	60.00	470.00
Research	Explicit	Real	Average	Social	1	<0	
Research	Explicit	Real	Average	Social	2	79.00	96.00
Research	Explicit	Real	Average	Social	2	60.10	82.30
Research	Explicit	Real	Average	Social	2	11.10	11.90
Research	Implicit	Nominal	Average	Social	1	63.30	63.30
Both	Explicit	Nominal	Average	Social	1	28.90	28.90
Both	Explicit	Real	Average	Social	2	23.70	23.80
Both	Implicit	Real	Average	Social	4	34.00	51.00
Both	Implicit	Real	Average	Social	3	31.70	43.20
Both	Implicit	Real	Average	Social	3	44.10	51.50
Both	Implicit	Real	Average	Social	2	-47.50	14.20
Both	Explicit	Real	Average	Social	2	34.00	37.00
Both	Explicit	Nominal	Average	Social	6	5.70	48.69
Research	Explicit	Nominal	Average	Social	6	1.40	35.12
Both	Explicit	Nominal	Average	Social	6	35.83	47.58
Research	Explicit	Nominal	Average	Social	6	17.85	32.38
Both	Explicit	Nominal	Average	Social	2	104.43	104.81
Research	Explicit	Nominal	Average	Social	2	69.36	70.63
Both	Explicit	Nominal	Average	Social	2	33.83	35.59
Research	Explicit	Nominal	Average	Social	2	11.44	21.26
Both	Explicit	Nominal	Average	Social	2	33.28	34.75
Research	Explicit	Nominal	Average	Social	2	24.03	26.11
Both	Explicit	Real	Average	Social	5	32.00	77.00
Research	Direct	Nominal	Marginal	Social	1	55.00	55.00
Both	Explicit	Real	Average	Social	1	97.40	97.40
Research	Explicit	Real	Average	Social	3	82.00	102.00
Both	Explicit	Real	Average	Social	1	79.00	79.00
Research	Explicit	Real	Average	Social	1	84.20	84.20
Both	Explicit	Real	Average	Social	4	27.00	33.00
Research	Explicit	Real	Average	Social	1	46.00	46.00
Both	Explicit	Real	Average	Social	4	17.10	21.80
Research	Explicit	Real	Average	Social	4	23.20	26.50
Research	Implicit	Real	Average	Social	2	113.00	125.00
Both	Direct	Real	Average	Social	1	15.00	15.00
Research	Explicit	Real	Average	Social	2	99.00	101.00
Research	Implicit	Real	Average	Social	1	176.40	176.40
Research	Explicit	Real	Average	Social	6	34.00	49.00
Research	Implicit	Real	Average	Social	8	17.00	45.00
Research	Explicit	Nominal	Average	Social	6	79.00	101.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
1979	Davis J.	Government/University	United States	All United States	All agriculture
*1979	Evenson R.	Government/University	United States	All United States	All agriculture
*1979	Evenson R.	Government/University	United States	All United States	All agriculture
*1979	Knutson M.	Other	United States	All United States	All agriculture
*1979	Pray C.	Government	Asia/Pacific	Bangladesh	Other crops
*1979	Pray C.	Government	Asia/Pacific	Bangladesh	Other crops
*1979	Pray C.	Government	Asia/Pacific	Bangladesh	Rice
*1979a	White F.	Government/University	United States	U.S. state	All agriculture
*1979b	White F.	Other	United States	All United States	All agriculture
*1980	Evenson R.	Government/University	United States	All United States	All agriculture
*1980	Evenson R.	Government/University	United States	All United States	All agriculture
*1980	Evenson R.	Government/University	United States	U.S. state	All agriculture
*1980	Sim R.	Government/University	United States	All United States	Wheat
*1980	Sim R.	Government/University	United States	U.S. state	Wheat
*1980	Sim R.	Government/University	United States	U.S. state	Wheat
*1980	Sundquist W.	University	United States	All United States	Maize
*1980	Sundquist W.	University	United States	All United States	Other crops
*1980	Sundquist W.	University	United States	All United States	Wheat
1981	Araji A.	University	United States	All United States	Beans
1981	Araji A.	University	United States	All United States	Beans
1981	Araji A.	University	United States	All United States	Beef
1981	Araji A.	University	United States	All United States	Beef
1981	Araji A.	University	United States	All United States	Forestry
1981	Araji A.	University	United States	All United States	Forestry
1981	Araji A.	University	United States	All United States	Fruit, nut
1981	Araji A.	University	United States	All United States	Fruit, nut
1981	Araji A.	University	United States	All United States	Maize
1981	Araji A.	University	United States	All United States	Maize
1981	Araji A.	University	United States	All United States	Other crops
1981	Araji A.	University	United States	All United States	Other crops
1981	Araji A.	University	United States	All United States	Pasture
1981	Araji A.	University	United States	All United States	Pasture
1981	Araji A.	University	United States	All United States	Potato
1981	Araji A.	University	United States	All United States	Potato
1981	Araji A.	University	United States	All United States	Sorghum
1981	Araji A.	University	United States	All United States	Sorghum
1981	Araji A.	University	United States	All United States	Wheat
1981	Araji A.	University	United States	All United States	Wheat
*1981	Avila A.	Government	Latin America/Caribbean	Brazil	Rice
*1981	Avila A.	Government	Latin America/Caribbean	Brazil	Rice
*1981	Moricochi L.	Government	Latin America/Caribbean	Brazil	Fruit, nut
*1981	Norton G.	University	United States	All United States	Dairy
*1981	Norton G.	University	United States	All United States	Other crops
*1981	Norton G.	University	United States	All United States	Other livestock
*1981	Norton G.	University	United States	All United States	Poultry
*1981	Otto D.	Government	United States	All United States	Maize

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Direct	Real	Marginal	Social	10	28.70	100.00
Extension	Direct	Nominal	Average	Social	1	110.00	110.00
Research	Direct	Nominal	Average	Social	7	45.00	130.00
Both	Direct	Real	Marginal	Social	8	28.00	49.70
Both	Explicit	Real	Average	Social	2	30.00	50.00
Research	Explicit	Real	Average	Social	2	37.50	60.00
Research	Explicit	Real	Average	Social	1	32.50	32.50
Both	Direct	Real	Marginal	Social	2	39.80	50.80
Both	Direct	Real	Marginal	Social	3	41.70	54.80
Extension	Direct	Real	Marginal	Social	1	110.00	110.00
Research	Direct	Real	Marginal	Social	3	65.00	110.00
Research	Direct	Real	Marginal	Social	3	55.00	130.00
Research	Direct	Nominal	Marginal	Social	5	25.23	61.96
Research	Direct	Nominal	Marginal	Social	9	36.00	57.00
Research	Explicit	Nominal	Average	Social	2	27.00	42.00
Research	Direct	Nominal	Marginal	Social	1	115.00	115.00
Research	Direct	Nominal	Marginal	Social	1	118.00	118.00
Research	Direct	Nominal	Marginal	Social	1	97.00	97.00
Both	Implicit	Nominal	Average	Social	2	3.91	11.61
Research	Implicit	Nominal	Average	Social	3	4.30	7.30
Both	Implicit	Nominal	Average	Social	2	18.95	23.35
Research	Implicit	Nominal	Average	Social	2	5.80	8.18
Both	Implicit	Nominal	Average	Social	1	86.97	86.97
Research	Implicit	Nominal	Average	Social	1	61.43	61.43
Both	Implicit	Nominal	Average	Social	11	11.88	102.50
Research	Implicit	Nominal	Average	Social	8	2.10	35.24
Both	Implicit	Nominal	Average	Social	1	59.26	59.26
Research	Implicit	Nominal	Average	Social	3	14.63	17.04
Both	Implicit	Nominal	Average	Social	16	1.72	161.20
Research	Implicit	Nominal	Average	Social	8	1.20	48.00
Both	Implicit	Nominal	Average	Social	2	36.66	38.51
Research	Implicit	Nominal	Average	Social	3	8.07	17.20
Both	Implicit	Nominal	Average	Social	2	39.82	44.90
Research	Implicit	Nominal	Average	Social	3	1.05	10.06
Both	Implicit	Nominal	Average	Social	1	112.90	112.90
Research	Implicit	Nominal	Average	Social	1	74.42	74.42
Both	Implicit	Nominal	Average	Social	1	191.00	191.00
Research	Implicit	Nominal	Average	Social	1	134.20	134.20
Both	Explicit	Real	Average	Social	1	96.00	96.00
Research	Explicit	Real	Average	Social	1	107.00	107.00
Both	Explicit	Real	Average	Social	2	24.69	27.61
Research	Direct	Real	Marginal	Social	10	27.00	62.00
Research	Direct	Real	Marginal	Social	10	31.00	85.00
Research	Direct	Real	Marginal	Social	10	56.00	132.00
Research	Direct	Real	Marginal	Social	5	30.00	56.00
Extension	Direct	Nominal	Marginal	Social	3	58.20	87.30

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
*1981	Otto D.	Government	United States	All United States	Maize
*1981	Otto D.	Government	United States	All United States	Other crops
*1981	Otto D.	Government	United States	All United States	Sorghum
*1981	Otto D.	Government	United States	All United States	Sorghum
*1981	Otto D.	Government	United States	All United States	Wheat
*1981	Otto D.	Government	United States	All United States	Wheat
*1981	Otto D.	Government	United States	U.S. state	Maize
*1981	Otto D.	Government	United States	U.S. state	Maize
*1981	Otto D.	Government	United States	U.S. state	Other crops
*1981	Otto D.	Government	United States	U.S. state	Other crops
*1981	Otto D.	Government	United States	U.S. state	Wheat
*1981	Otto D.	Government	United States	U.S. state	Wheat
*1981	Pazols I.	Government	Latin America/Caribbean	Chile	Rice
*1982	Barker R.	International	Asia/Pacific	Philippines	Rice
*1982	Blakeslee L.	Other	United States	U.S. state	Wheat
1982	Coffey J.	University	United States	U.S. state	All agriculture
1982	Coffey J.	University	United States	U.S. state	All agriculture
*1982	Evenson. R.	Government	Latin America/Caribbean	Brazil	Unspecified
*1982	Yrarrazaval R.	Government/Private	Latin America/Caribbean	Chile	Maize
*1982	Yrarrazaval R.	Government/Private	Latin America/Caribbean	Chile	Wheat
*1982	Zentner R.	Government	Canada	Canada	Wheat
*1982	Da Cruz E.	Government	Latin America/Caribbean	Brazil	Unspecified
1982	White F.	Government/University	United States	All United States	All agriculture
*1983	Araji A.	Other	United States	All United States	Beef
*1983	Araji A.	Other	United States	All United States	Swine
*1983	Martinez J.	Government	Latin America/Caribbean	Panama	Maize
*1983	Smith B.	University	United States	All United States	Other crops
*1983	Smith B.	University	United States	All United States	Other livestock
*1983	Smith B.	University	United States	All United States	Poultry
*1983	Smith B.	University	United States	U.S. state	Dairy
*1984	Avila A.	Government	Latin America/Caribbean	Brazil	All agriculture
1984a	Dyer P.	Government	Other developed countries	New Zealand	Dairy
1984b	Dyer P.	Government	Other developed countries	New Zealand	Forestry
*1984	Lyu S.-J.	Other	United States	All United States	All agriculture
*1984	Lyu S.-J.	Other	United States	U.S. state	All agriculture
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	All crops
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	All crops
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	Maize
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	Maize
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	Wheat
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	Wheat
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	Wheat
*1984	Nagy J.	Government	Asia/Pacific	Pakistan	Wheat
1984	Norton G.	University	United States	U.S. state	All agriculture
1984	Norton G.	University	United States	U.S. state	All agriculture
*1984	Pinazza A.	Government	Latin America/Caribbean	Brazil	Other crops

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Direct	Nominal	Marginal	Social	3	162.40	177.70
Research	Direct	Nominal	Marginal	Social	3	150.20	176.40
Extension	Direct	Nominal	Marginal	Social	3	42.10	63.20
Research	Direct	Nominal	Marginal	Social	3	101.20	134.10
Extension	Direct	Nominal	Marginal	Social	3	48.70	73.10
Research	Direct	Nominal	Marginal	Social	3	80.60	126.30
Extension	Direct	Nominal	Marginal	Social	2	49.30	73.90
Research	Direct	Nominal	Marginal	Social	2	87.10	291.40
Extension	Direct	Nominal	Marginal	Social	2	19.80	29.70
Research	Direct	Nominal	Marginal	Social	1	233.70	233.70
Extension	Direct	Nominal	Marginal	Social	4	8.80	95.80
Research	Direct	Nominal	Marginal	Social	3	78.80	148.10
Both	Explicit	Real	Average	Social	7	15.90	93.90
Both	Implicit	Real	Average	Social	4	35.00	85.00
Both	Implicit	Real	Average	Social	8	–14.90	26.70
Extension	Direct	Real	Marginal	Social	1	48.00	48.00
Research	Direct	Real	Marginal	Social	1	58.00	58.00
Research	Direct	Real	Marginal	Social	1	69.00	69.00
Both	Explicit	Real	Average	Social	4	31.61	33.63
Both	Explicit	Real	Average	Social	4	21.18	28.19
Research	Explicit	Real	Average	Social	6	26.00	71.00
Research	Implicit	Real	Average	Social	2	28.90	42.80
Research	Direct	Real	Marginal	Social	6	6.90	36.00
Research	Explicit	Real	Average	Social	1	68.00	68.00
Research	Explicit	Real	Average	Social	1	143.00	143.00
Research	Implicit	Real	Average	Social	8	47.00	325.00
Research	Direct	Nominal	Marginal	Social	2	202.00	307.90
Research	Direct	Nominal	Marginal	Social	2	22.30	43.30
Research	Direct	Nominal	Marginal	Social	2	25.50	60.90
Research	Direct	Nominal	Marginal	Social	2	24.87	38.78
Both	Implicit	Real	Average	Social	1	27.20	27.20
Research	Explicit	Real	Average	Social	1	17.20	17.20
Research	Direct	Real	Average	Social	1	11.86	11.86
Both	Direct	Real	Marginal	Social	2	66.00	83.00
Both	Direct	Real	Marginal	Social	20	30.00	169.00
Both	Direct	Real	Marginal	Social	2	56.20	64.50
Research	Direct	Real	Marginal	Social	2	77.60	85.60
Both	Explicit	Nominal	Average	Social	1	19.00	19.00
Research	Explicit	Nominal	Average	Social	1	23.00	23.00
Both	Explicit	Nominal	Average	Social	1	58.00	58.00
Both	Explicit	Nominal	Marginal	Social	1	64.00	64.00
Research	Explicit	Nominal	Average	Social	1	68.00	68.00
Research	Explicit	Nominal	Marginal	Social	1	81.00	81.00
Extension	Direct	Real	Marginal	Social	1	48.00	48.00
Research	Direct	Real	Marginal	Social	1	58.00	58.00
Research	Implicit	Real	Average	Social	1	35.14	35.14

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
*1984	Zentner R.	Government/University	Canada	Canada	Wheat
*1984	Zentner R.	Government/University	Canada	Canada	Wheat
*1984	Zentner R.	Government/University	Canada	Canada	Wheat
1985	Ayres C.	Government/Private	Latin America/Caribbean	Brazil	Other crops
1985	Ayres C.	Government/Private	Latin America/Caribbean	Brazil	Other crops
*1985	Bare B.	Other	United States	U.S. state	Forestry
*1985	Bengston D.	Government/Private	United States	All United States	Forestry
*1985	Brinkman G.	Private	Canada	Canada	Crops and livestock
*1985	Doyle C.	Other	Europe	United Kingdom	All agriculture
*1985	Farrell C.	Other	Canada	Canada	Barley
*1985	Farrell C.	Other	Canada	Canada	Maize
*1985	Farrell C.	Other	Canada	Canada	Other crops
*1985	Farrell C.	Other	Canada	Canada	Wheat
*1985	Herruzo A.	Government	Europe	Spain	Rice
*1985	Monteiro A.	Government	Latin America/Caribbean	Brazil	Other tree
*1985	Nagy J.	Government	Asia/Pacific	Pakistan	All crops
*1985	Ulrich A.	Government	Canada	Canada	Barley
*1985	Ulrich A.	Government	Canada	Canada	Pasture
*1985	Ulrich A.	Government	Canada	Canada	Wheat
*1985	Da Cruz E.	Government	Latin America/Caribbean	Brazil	Unspecified
*1986	Ambrosi I.	Government	Latin America/Caribbean	Brazil	Other crops
*1986	Boyle G.	Government/University	Europe	Ireland	All agriculture
*1986	Braha H.	Government/University	United States	All United States	All agriculture
*1986	Da Silva M.	Government	Latin America/Caribbean	Brazil (state)	Crops and livestock
*1986	Eveleens W.	Government/Private	Other developed countries	New Zealand	All agriculture
*1986	Irias L.	Government	Latin America/Caribbean	Brazil	Unspecified
*1986	Khan M.	Government	Asia/Pacific	Pakistan	All crops
*1986	Martinez S.	Other	United States	All United States	Poultry
*1986	Martinez S.	Other	United States	All United States	Poultry
*1986	Newman D.	Government/Private	United States	U.S. state	Forestry
*1986	Stranahan J.	Government/Private	United States	U.S. state	Fruit, nut
*1986	Ulrich A.	Government/Private	Canada	Canada	Barley
*1986	Ulrich A.	Government/Private	Canada	Canada	Barley
*1986	Unnevehr L.	Government	Asia/Pacific	Indonesia	Rice
*1986	Unnevehr L.	International	Asia/Pacific	Philippines	Rice
*1986	Westgate R.	Private	United States	All United States	Forestry
*1987	Finn P.	Government	Canada	Canada	Barley
*1987	Finn P.	Government	Canada	Canada	Other crops
*1987	Finn P.	Government	Canada	Canada	Pasture
*1987	Finn P.	Government	Canada	Canada	Wheat
*1987	Fox G.	Government	Canada	Canada	Dairy
*1987	Fox G.	Government	Canada	Canada	Dairy
*1987	Fox G.	Government	Canada	Canada	Poultry
*1987	Fox G.	Government	Canada	Canada	Poultry

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Both	Explicit	Real	Average	Social	2	30.00	34.00
Research	Explicit	Real	Average	Social	2	34.00	39.00
Research	Explicit	Real	Marginal	Social	2	44.00	59.00
Research	Explicit	Real	Average	Social	15	43.00	57.00
Research	Explicit	Real	Marginal	Social	3	40.00	49.00
Research	Implicit	Real	Average	Social	4	9.30	12.10
Research	Implicit	Real	Average	Social	2	34.00	40.00
Both	Implicit	Real	Average	Social	18	54.50	84.60
Research	Direct	Real	Average	Social	9	10.50	31.50
Research	Implicit	Real	Average	Social	6	14.60	40.70
Research	Implicit	Real	Average	Social	4	19.60	22.90
Research	Implicit	Real	Average	Social	4	16.50	22.90
Research	Implicit	Real	Average	Social	2	40.80	41.90
Both	Explicit	Real	Average	Social	2	17.00	18.00
Both	Explicit	Real	Average	Social	1	57.00	57.00
Both	Direct	Real	Marginal	Social	2	39.00	64.50
Research	Explicit	Real	Average	Social	3	19.00	22.00
Research	Explicit	Real	Average	Social	1	14.00	14.00
Research	Explicit	Real	Average	Social	3	19.00	29.00
Research	Implicit	Real	Average	Social	1	27.80	27.80
Research	Implicit	Real	Average	Social	2	59.00	74.20
Research	Explicit	Real	Average	Social	1	26.00	26.00
Both	Direct	Real	Marginal	Social	1	47.21	47.21
Both	Direct	Real	Marginal	Social	4	15.00	66.00
Research	Implicit	Real	Average	Social	1	22.20	22.20
Both	Direct	Real	Marginal	Social	1	36.00	36.00
Research	Explicit	Nominal	Average	Private	4	92.00	455,290.00
Research	Explicit	Nominal	Average	Social	4	321.00	724,323.00
Both	Explicit	Real	Average	Social	12	0.28	8.24
Research	Direct	Nominal	Marginal	Social	1	57.40	57.40
Research	Explicit	Real	Average	Private	4	0.00	33.00
Research	Explicit	Real	Average	Social	4	31.00	75.00
Research	Explicit	Nominal	Average	Social	1	37.00	37.00
Research	Explicit	Nominal	Average	Social	1	29.00	29.00
Research	Implicit	Real	Average	Social	12	37.30	111.20
Research	Implicit	Real	Average	Social	1	49.70	49.70
Research	Explicit	Nominal	Average	Social	1	22.00	22.00
Research	Explicit	Nominal	Average	Social	1	51.00	51.00
Research	Explicit	Nominal	Average	Social	1	14.00	14.00
Research	Explicit	Nominal	Average	Social	1	29.00	29.00
Research	Explicit	Nominal	Average	Social	3	106.10	117.30
Research	Explicit	Nominal	Marginal	Social	3	95.70	109.10
Research	Explicit	Nominal	Average	Social	4	115.60	124.20
Research	Explicit	Nominal	Marginal	Social	4	114.70	130.60

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Subregion	Commodity[c]
1987	Fox G.	Government	Canada	Canada	Sheep, goats
*1987	Fox G.	Government	Canada	Canada	Sheep, goats
*1987	Fox G.	Government	Canada	Canada	Swine
*1987	Fox G.	Government	Canada	Canada	Swine
*1987	Furtan W.	Government	Canada	Canada	Other crops
*1987a	Librero A.	Government	Asia/Pacific	Philippines	Maize
*1987a	Librero A.	Government	Asia/Pacific	Philippines	Maize
*1987b	Librero A.	Government/University	Asia/Pacific	Philippines	Other crops
*1987	Norton G.	Government	Latin America/Caribbean	Peru	Beans
*1987	Norton G.	Government	Latin America/Caribbean	Peru	Maize
*1987	Norton G.	Government	Latin America/Caribbean	Peru	Other crops
*1987	Norton G.	Government	Latin America/Caribbean	Peru	Potato
*1987	Norton G.	Government	Latin America/Caribbean	Peru	Rice
*1987	Norton G.	Government	Latin America/Caribbean	Peru	Wheat
*1987	Scobie G.	Government	Other developed countries	New Zealand	All agriculture
1987	Sumelius J.	Government/University	Europe	Finland	All agriculture
*1987	Ulrich A.	Other	Canada	Canada	Wheat
*1988	Antony G.	Other	Multiple locations	Australia/Papua-New Guinea	Other tree
1988	Horbasz C.	Government	Canada	Canada	Sheep, goats
1988	Norgaard R.	Government/International	Africa	Unknown	Cassava
*1988	Power A.	Government	Europe	United Kingdom	Poultry
*1988	Romano L.	Government	Latin America/Caribbean	Colombia	Crops and livestock
*1988	Romano L.	Government	Latin America/Caribbean	Colombia	Crops and livestock
*1988	Scobie G.	Government	Latin America/Caribbean	Honduras	Fruit, nut
*1988	Scobie G.	Government	Latin America/Caribbean	Honduras	Fruit, nut
*1988	Scobie G.	Government	Latin America/Caribbean	Honduras	Other crops
*1988a	Thirtle C.	Government	Europe	United Kingdom	All agriculture
1988b	Thirtle C.	Government	Europe	United Kingdom	All agriculture
*1988	Widmer L.	Government	Canada	Canada	Beef
*1988	Widmer L.	Government	Canada	Canada	Beef
*1989	Araji A.	University	United States	U.S. state	Wheat
*1989	Brennan J.	Government	Australia	Australia	Wheat
*1989	Cordomi M.	Government	Latin America/Caribbean	Argentina	All agriculture
*1989	Cordomi M.	University	Latin America/Caribbean	Argentina	Other crops
*1989	Echeverría R.	Government/Private	Latin America/Caribbean	Uruguay	Rice
*1989	Enamul Haque A.	Government	Canada	Canada	Poultry
*1989	Enamul Haque A.	Government	Canada	Canada	Poultry
1989	Huffman W.	Other	United States	All United States	Other crops
*1989	Lanzer E.	Government	Latin America/Caribbean	Brazil (south)	All agriculture
*1989	Norton G.	University	Latin America/Caribbean	Eastern Caribbean	Fruit, nut
*1989	Norton G.	University	Latin America/Caribbean	Eastern Caribbean	Other crops
*1989	Norton G.	University	Latin America/Caribbean	Eastern Caribbean	Other crops
*1989	Norton G.	University	Latin America/Caribbean	Eastern Caribbean	Other tree

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Explicit	Nominal	Average	Social	2	20.80	25.30
Research	Explicit	Nominal	Marginal	Social	2	30.70	34.60
Research	Explicit	Nominal	Average	Social	2	43.40	49.60
Research	Explicit	Nominal	Marginal	Social	2	43.30	47.80
Research	Explicit	Real	Average	Social	3	41.00	51.00
Both	Direct	Real	Marginal	Social	12	27.00	49.00
Research	Direct	Real	Marginal	Social	12	29.00	58.00
Both	Direct	Nominal	Marginal	Social	3	51.00	71.00
Both	Explicit	Nominal	Average	Social	4	14.00	24.00
Both	Explicit	Nominal	Average	Social	4	10.00	31.00
Both	Explicit	Nominal	Average	Social	4	17.00	38.00
Both	Explicit	Nominal	Average	Social	4	22.00	42.00
Both	Explicit	Nominal	Average	Social	6	17.00	44.00
Both	Explicit	Nominal	Average	Social	4	18.00	36.00
Both	Direct	Real	Marginal	Social	4	15.00	66.00
Both	Implicit	Real	Marginal	Social	6	20.90	76.80
Research	Implicit	Nominal	Average	Social	4	53.00	93.00
Research	Explicit	Real	Average	Social	2	21.59	677.00
Research	Explicit	Real	Marginal	Social	2	20.02	25.31
Research	Implicit	Real	Average	Social	1	1,490.00	1,490.00
Both	Implicit	Real	Average	Social	8	75.65	122.20
Both	Direct	Real	Marginal	Social	2	72.00	85.55
Both	Implicit	Real	Average	Social	1	141.00	141.00
Research	Explicit	Real	Average	Social	6	16.20	92.80
Research	Implicit	Real	Average	Social	2	22.60	28.10
Research	Implicit	Real	Average	Social	4	17.10	76.30
Research	Direct	Real	Marginal	Social	21	15.00	83.60
Both	Direct	Nominal	Marginal	Social	7	59.00	260.00
Research	Explicit	Nominal	Average	Social	2	61.50	65.80
Research	Explicit	Nominal	Marginal	Social	2	59.00	63.00
Research		Real	Average	Social	3	29.00	71.00
Research	Implicit	Real	Average	Social	4	19.20	23.60
Both	Direct	Nominal	Marginal	Social	1	41.50	41.50
Research	Direct	Nominal	Marginal	Social	2	33.00	37.85
Research	Implicit	Real	Average	Social	1	52.00	52.00
Research	Explicit	Real	Average	Social	12	75.13	98.12
Research	Explicit	Real	Marginal	Social	6	83.57	91.40
Research	Direct	Real	Marginal	Social	1	62.00	62.00
Research	Implicit	Real	Average	Social	1	42.80	42.80
Both	Explicit	Real	Average	Social	3	21.00	28.00
Both	Explicit	Real	Average	Social	6	3.00	70.00
Both	Implicit	Real	Average	Social	2	53.00	83.00
Both	Explicit	Real	Average	Social	2	50.00	65.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
1989	Ojemakinde A.	Government/University	United States	U.S. state	Crops and livestock
1989	Ojemakinde A.	Government/University	United States	U.S. state	Crops and livestock
*1989	Ribeiro S.	Private	Asia/Pacific	India	Millet
*1989	Ribeiro S.	Private	Asia/Pacific	India	Millet
*1989	Ribeiro S.	Private	Asia/Pacific	India	Sorghum
*1989	Ribeiro S.	Private	Asia/Pacific	India	Sorghum
*1989	Schwartz L.	Government	Africa	Senegal	Beans
1989	Thirtle C.	Government	Europe	United Kingdom	All agriculture
*1989	Zachariah O.	Government	Canada	Canada	Poultry
*1989	Zachariah O.	Government	Canada	Canada	Poultry
*1989	Embrapa	Government	Latin America/Caribbean	Brazil (northeast)	Crops and livestock
*1990a	Antony G.	Other	Asia/Pacific	Papua-New Guinea	Other tree
*1990a	Antony G.	Other	Asia/Pacific	Papua-New Guinea	Other tree
*1990b	Antony G.	Other	Asia/Pacific	Papua-New Guinea	Other tree
*1990c	Antony G.	Other	Asia/Pacific	Papua-New Guinea	Other tree
1990a	Araji A.	University	United States	U.S. state	Unspecified
1990b	Araji A.	University	United States	U.S. state	Unspecified
*1990a	Doeleman J.	Government/University	Multiple locations	Australia, Asia/Pacific	Rice
*1990b	Doeleman J.	Government	Multiple locations	Australia, Asia/Pacific	Fruit, nut
*1990	Fox G.	Government	Canada	Canada	Poultry
*1990	Fox G.	Government	Canada	Canada	Poultry
*1990	Horton D.	Government/International	West Asia, North Africa	Tunisia	Potato
1990	Jarvis L.	Government/International	Latin America/Caribbean	Unknown	Pasture
1990	Karanja D.	Government	Africa	Kenya	Maize
1990	Karanja D.	Government	Africa	Kenya	Maize
*1990	Librero A.	Government/University	Asia/Pacific	Philippines	Poultry
*1990	Librero A.	Government/University	Asia/Pacific	Philippines	Poultry
*1990	Macagno L.	Government	United States	U.S. state	Barley
1990	MacMillan J.	Other	Canada	Canada	Other crops
*1990	Pray C.	Private	Asia/Pacific	India	Millet
*1990	Pray C.	Private	Asia/Pacific	India	Millet
*1990	Ruiz de Londono N.	Government	Latin America/Caribbean	Peru/Colombia	Beans
*1990	Ruiz de Londono N.	Government/International	Latin America/Caribbean	Peru/Colombia	Beans
*1990	Ruiz de Londono N.	International	Latin America/Caribbean	Peru/Colombia	Beans
1990	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1990	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1990	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1990	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1990	Sere C.	Government	Latin America/Caribbean	Tropical	Pasture
*1990	Tobin J.	Government	Australia	Australia	Fruit, nut
*1990	Traxler G.	Government	Latin America/Caribbean	Mexico	Wheat

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Extension	Direct	Nominal	Marginal	Social	1	15.70	15.70
Research	Direct	Nominal	Marginal	Social	1	19.61	19.61
Research	Explicit	Real	Average	Private	2	55.00	57.00
Research	Explicit	Real	Average	Social	4	174.00	179.00
Research	Explicit	Real	Average	Private	2	6.00	24.00
Research	Explicit	Real	Average	Social	5	35.00	41.00
Both	Implicit	Nominal	Average	Social	1	63.00	63.00
Both	Direct	Real	Marginal	Social	6	59.00	100.00
Research	Explicit	Nominal	Average	Social	6	46.60	62.50
Research	Explicit	Nominal	Marginal	Social	6	47.90	60.20
Research	Implicit	Real	Average	Social	1	27.90	27.90
Research		Real	Average	Private	8	20.00	1,000.00
Research	Explicit	Real	Average	Private	2	33.00	39.00
Research	Explicit	Real	Average	Private	2	58.00	143.00
Research	Explicit	Real	Average	Private	8	29.00	104.00
Both	Explicit	Nominal	Average	Social	4	16.40	57.60
Both	Implicit	Real	Average	Social	1	23.39	23.39
Research	Implicit	Nominal	Average	Social	1	466.00	466.00
Research	Implicit	Nominal	Average	Social	3	32.00	130.00
Research	Explicit	Real	Average	Social	3	66.00	77.80
Research	Explicit	Real	Marginal	Social	3	64.00	64.30
Research	Implicit	Real	Average	Social	1	80.00	80.00
Research	Explicit	Real	Average	Social	2	16.00	26.00
Research	Direct	Real	Average	Social	1	68.10	68.10
Research	Direct	Real	Marginal	Social	1	40.90	40.90
Research	Direct	Nominal	Marginal	Social	5	124.00	429.50
Research	Direct	Real	Marginal	Social	5	111.50	526.00
Both	Explicit	Real	Average	Social	3	62.70	85.20
n.a.	Explicit	Real	Average	Private	1	270.00	270.00
Research	Explicit	Nominal	Average	Private	1	20.00	20.00
Research	Explicit	Nominal	Average	Social	1	170.00	170.00
Research	Implicit	Nominal	Average	Social	1	29.00	29.00
Research	Implicit	Nominal	Average	Social	1	15.20	15.20
Research	Implicit	Nominal	Average	Social	1	22.50	22.50
Research	Explicit	Real	Average	Private	4	20.00	26.00
Research	Explicit	Real	Average	Social	4	6.50	12.00
Research	Explicit	Real	Marginal	Private	4	14.00	19.00
Research	Explicit	Real	Marginal	Social	4	2.50	6.75
Research	Explicit	Real	Average	Social	6	15.00	100.00
Research	Implicit	Real	Average	Social	6	210.00	1,736.00
Both	Explicit	Real	Average	Social	4	22.00	24.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Subregion	Commodity[c]
*1990	Traxler G.	Government	Latin America/Caribbean	Mexico	Wheat
*1990	Unnevehr L.	International	Asia/Pacific	Philippines	Rice
*1990	Young R.	Government	Australia	Australia	Forestry
*1991	Azam Q.	Government/University	Asia/Pacific	Pakistan	All crops
*1991	Azam Q.	Government/University	Asia/Pacific	Pakistan	Maize
*1991	Azam Q.	Government/University	Asia/Pacific	Pakistan	Other crops
*1991	Azam Q.	Government/University	Asia/Pacific	Pakistan	Other crops
*1991	Azam Q.	Government/University	Asia/Pacific	Pakistan	Rice
*1991	Azam Q.	Government/University	Asia/Pacific	Pakistan	Wheat
1991	Brennan J.	Other	Australia	Australia	Wheat
*1991	Chamala S.	Government/University	Multiple locations	Australia/India	Sorghum
*1991	Chavas J.-P.	Private	United States	All United States	All agriculture
*1991a	Chudleigh P.	Government	Australia	Australia	Dairy and beef
*1991b	Chudleigh P.	Government	Australia	Australia	Other crops
*1991c	Chudleigh P.	Private	Australia	Australia	Other crops
*1991c	Chudleigh P.	Private	Australia	Australia	Other crops
1991	Dey M.	Government	Asia/Pacific	Bangladesh	Other crops
1991	Dey M.	Government	Asia/Pacific	Bangladesh	Potato
1991	Dey M.	Government	Asia/Pacific	Bangladesh	Rice
1991	Dey M.	Government	Asia/Pacific	Bangladesh	Wheat
1991	Evenson R.	Government/Private	Asia/Pacific	India	All crops
1991	Evenson R.	Government/Private	Asia/Pacific	India	All crops
1991	Evenson R.	Government/Private	Asia/Pacific	India	Maize
1991	Evenson R.	Government/Private	Asia/Pacific	India	Maize
1991	Evenson R.	Government/Private	Asia/Pacific	India	Other crops
1991	Evenson R.	Government/Private	Asia/Pacific	India	Other crops
1991	Evenson R.	Government/Private	Asia/Pacific	India	Rice
1991	Evenson R.	Government/Private	Asia/Pacific	India	Rice
1991	Evenson R.	Government/Private	Asia/Pacific	India	Wheat
1991	Evenson R.	Government/Private	Asia/Pacific	India	Wheat
*1991	Fleming E.	University	Australia	Australia	Dairy
*1991	Ito J.	Government	Other developed countries	Japan	All agriculture
*1991	Johnston J.	Government	Multiple locations	Australia, Asia/Pacific	Poultry
*1991	Khan A.	Government	Latin America/Caribbean	Brazil	Cassava
*1991	Khan A.	Government	Latin America/Caribbean	Brazil	Cassava
1991	Leiby J.	University	United States	U.S. state	All agriculture
1991	Mazzucato V.	Government	Africa	Kenya	Maize
1991	Norton G.	Government/University	United States	All United States	All agriculture
1991	Norton G.	Government/University	United States	All United States	Fruit, nuts
1991	Norton G.	Government/University	United States	All United States	Other crops
1991	Norton G.	Government/University	United States	All United States	Other livestock
1991	Norton G.	Government/University	United States	All United States	Poultry
1991	Page J.	Government	Australia	Australia	Other crops
1991	Page J.	Government	Australia	Australia	Pigeon, chickpea

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Explicit	Real	Average	Social	1	31.00	31.00
Research	Explicit	Nominal	Average	Social	1	61.00	61.00
Research	Implicit	Nominal	Average	Social	6	19.00	457.00
Research	Direct	Real	Marginal	Social	10	39.00	88.00
Research	Direct	Real	Marginal	Social	1	46.00	46.00
Research	Direct	Real	Marginal	Social	1	<0	
Research	Direct	Real	Marginal	Social	5	44.00	102.00
Research	Direct	Real	Marginal	Social	1	89.00	89.00
Research	Direct	Real	Marginal	Social	1	76.00	76.00
Research	Implicit	Real	Average	Social	2	19.20	23.00
Research	Explicit	Real	Average	Social	4	15.00	57.00
Research	Direct	Real	Marginal	Social	2	36.00	41.00
Research	Explicit	Real	Average	Social	2	26.00	68.00
Research	Explicit	Real	Average	Social	1	43.00	43.00
Both	Explicit	Real	Average	Social	1	58.00	58.00
Research	Explicit	Real	Average	Social	1	25.00	25.00
Research	Direct	Nominal	Marginal	Social	5	25.00	143.00
Research	Direct	Nominal	Marginal	Social	1	129.00	129.00
Research	Direct	Nominal	Marginal	Social	1	165.00	165.00
Research	Direct	Nominal	Marginal	Social	1	85.00	85.00
Extension	Direct	Real	Marginal	Social	1	176.81	176.81
Research	Direct	Real	Marginal	Social	2	95.00	218.24
Extension	Direct	Real	Marginal	Social	1	56.21	56.21
Research	Direct	Real	Marginal	Social	1	94.28	94.28
Extension	Direct	Real	Marginal	Social	2	197.63	201.58
Research	Direct	Real	Marginal	Social	2	107.40	117.21
Extension	Direct	Real	Marginal	Social	1	215.76	215.76
Research	Direct	Real	Marginal	Social	1	155.55	155.55
Extension	Direct	Real	Marginal	Social	1	82.86	82.86
Research	Direct	Real	Marginal	Social	1	50.74	50.74
Research	Implicit	Real	Average	Social	1	102.00	102.00
Both	Direct	Real	Marginal	Social	2	22.20	37.40
Research	Implicit	Real	Average	Social	1	50.72	50.72
Both	Explicit	Real	Average	Social	9	26.94	44.25
Research	Explicit	Real	Average	Social	9	29.33	45.76
Research	Direct	Real	Marginal	Social	40	22.61	729.68
Research	Direct	Real	Marginal	Social	2	58.00	60.00
Research	Direct	Real	Marginal	Social	1	30.00	30.00
Research	Direct	Real	Marginal	Social	1	33.00	33.00
Research	Direct	Real	Marginal	Social	3	19.00	34.00
Research	Direct	Real	Marginal	Social	1	55.00	55.00
Research	Direct	Real	Marginal	Social	1	46.00	46.00
Research	Implicit	Real	Average	Social	13	25.70	147.70
Research	Implicit	Real	Average	Social	4	–1.30	99.10

(continued)

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
*1991	Ryland G.	Government	Multiple locations	Australia, Philippines, Malaysia	Other crops
*1991	Salmon D.	Government	Asia/Pacific	Indonesia	Rice
1991	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1991	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1991	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
1991	Scobie G.	Government/Private	Australia	Australia	Sheep, goats
*1991	Setboonsarng S.	Government	Asia/Pacific	Thailand	All crops
*1991	Tisdell C.	University	Australia	Australia	Fishery
*1992	Chavas J.-P.	Private	United States	All United States	All agriculture
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	All crops
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	All crops
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Cassava
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Groundnuts
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Groundnuts
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Maize
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Maize
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Other crops
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Other crops
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Rice
1992a	Evenson R.	Government	Asia/Pacific	Indonesia	Rice
1992b	Evenson R.	Government	Latin America/Caribbean	Brazil	Maize
1992b	Evenson R.	Government	Latin America/Caribbean	Brazil	Other crops
1992b	Evenson R.	Government	Latin America/Caribbean	Brazil	Wheat
1992b	Evenson R.	Government	Latin America/Caribbean	Brazil (Southern Cone)	Maize
1992b	Evenson R.	Government	Latin America/Caribbean	Brazil (Southern Cone)	Other crops
1992b	Evenson R.	Government	Latin America/Caribbean	Brazil (Southern Cone)	Wheat
*1992	Farquharson R.	Government	Australia	Australia	Beef
*1992	Fox G.	Government	Canada	Canada	Dairy
*1992	Fox G.	Government	Canada	Canada	Dairy
*1992	Hyde W.	Government	United States	All United States	Forestry
*1992	Hyde W.	Government	United States	All United States	forestry
*1992	Hyde W.	Government/Private	United States	U.S. state	Forestry
*1992	Ito J.	Government	Other developed countries	Japan	All agriculture
*1992	Ito J.	Government	Other developed countries	Japan	All agriculture
*1992	Johnston B.	Government	Australia	Australia	Fruit, nuts
*1992	Johnston B.	Government	Australia	Australia	Other crops
*1992	Johnston B.	Government	Australia	Australia	Pasture
*1992	Johnston B.	Government	Australia	Australia	Pigeon, chickpea
*1992	Johnston B.	Government	Australia	Australia	Wheat
*1992	Johnston B.	Government/University	Australia	Australia	Fruit, nuts

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Implicit	Nominal	Average	Social	2	29.90	37.80
Research	Direct	Real	Average	Social	1	151.00	151.00
Research	Explicit	Real	Average	Private	1	25.00	25.00
Research	Explicit	Real	Average	Social	1	9.50	9.50
Research	Explicit	Real	Marginal	Private	1	18.00	18.00
Research	Explicit	Real	Marginal	Social	1	5.00	5.00
Both	Direct	Nominal	Marginal	Social	1	40.00	40.00
Research	Implicit	Real	Average	Social	9	2.50	28.40
Research	Direct	Real	Marginal	Social	2	17.00	28.00
Extension	Direct	Nominal	Marginal	Social	2	50.00	92.00
Research	Direct	Nominal	Marginal	Social	2	201.00	240.00
Extension	Direct	Nominal	Marginal	Social	2	92.00	120.00
Extension	Direct	Nominal	Marginal	Social	1	47.00	47.00
Research	Direct	Nominal	Marginal	Social	2	130.00	205.00
Extension	Direct	Nominal	Marginal	Social	2	130.00	161.00
Research	Direct	Nominal	Marginal	Social	2	145.00	167.00
Extension	Direct	Nominal	Marginal	Social	2	126.00	160.00
Research	Direct	Nominal	Marginal	Social	2	166.00	204.00
Extension	Direct	Nominal	Marginal	Social	4	0.00	173.00
Research	Direct	Nominal	Marginal	Social	2	285.00	337.00
Research	Direct	Nominal	Marginal	Social	1	36.00	36.00
Research	Direct	Nominal	Marginal	Social	1	50.00	50.00
Research	Direct	Nominal	Marginal	Social	1	39.00	39.00
Research	Direct	Nominal	Marginal	Social	3	26.00	191.00
Research	Direct	Nominal	Marginal	Social	3	41.00	179.00
Research	Direct	Nominal	Marginal	Social	3	78.00	110.00
Both	Implicit	Real	Average	Social	4	10.00	30.00
Research	Explicit	Nominal	Average	Social	1	117.57	117.57
Research	Explicit	Nominal	Marginal	Social	1	104.83	104.83
Research	Explicit	Real	Average	Social	2	15.00	28.00
Research	Explicit	Real	Marginal	Social	2	3.08	16.00
Research	Explicit	Real	Average	Social	9	0.70	7.00
Research	Direct	Nominal	Marginal	Social	1	33.90	33.90
Research	Direct	Real	Marginal	Social	1	45.60	45.60
Both	Implicit	Real	Average	Social	2	28.30	28.60
Both	Implicit	Real	Average	Social	4	16.20	28.50
Both	Implicit	Real	Average	Social	6	13.50	20.00
Both	Implicit	Real	Average	Social	2	18.10	21.60
Both	Implicit	Real	Average	Social	3	179.20	290.00
Both	Implicit	Real	Average	Social	2	87.20	87.30

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Subregion	Commodity[c]
1992	MacMillan J.	Other	Africa	Zimbabwe	Maize
*1992	Macagno L.	University	United States	U.S. state	Barley
*1992	Pardey P.	Government	Asia/Pacific	Indonesia	Other crops
*1992	Pardey P.	Government	Asia/Pacific	Indonesia	Other crops
*1992	Pardey P.	Government	Asia/Pacific	Indonesia	Other crops
*1992	Pardey P.	Government	Asia/Pacific	Indonesia	Rice
*1992	Pardey P.	Government	Asia/Pacific	Indonesia	Rice
*1992	Rutten H.	Government	Europe	Netherlands	All agriculture
*1992	Scobie G.	Government	Australia	Australia	Sheep, goats
*1992a	Thirtle C.	Government	Africa	Zimbabwe	All agriculture
1992b	Thirtle C.	Government	Europe	United Kingdom	All agriculture
*1992	Traxler G.	Government	Latin America/Caribbean	Mexico	Wheat
*1992	Traxler G.	Government	Latin America/Caribbean	Mexico	Wheat
1992	Yee J.	Government/Private	United States	All United States	All agriculture
*1992	Da Cruz E.	Government	Latin America/Caribbean	Andean	Other crops
*1993	Ahmed M.	Other	Africa	Sudan	Sorghum
*1993a	Bindlish V.	Government	Africa	Burkina Faso	All crops
*1993b	Bindlish V.	Government	Africa	Kenya	All crops
1993	Byerlee D.	Government	Asia/Pacific	Pakistan	Wheat
1993	Byerlee D.	Government/International	Global	Global	Wheat
1993	Deininger K.	Government/University	United States	All United States	Crops and livestock
*1993	Howard J.	Government	Africa	Zambia	Maize
*1993	Howard J.	Government	Africa	Zambia	Maize
*1993	Howard J.	Government	Africa	Zambia	Maize
*1993	Howard J.	Government	Africa	Zambia	Maize
1993	Huffman W.	Government/University	United States	All United States	All agriculture
1993	Huffman W.	Government/University	United States	All United States	All agriculture
1993	Huffman W.	Government/University	United States	All United States	All crops
1993	Huffman W.	Government/University	United States	All United States	All crops
1993	Huffman W.	Government/University	United States	All United States	All livestock
1993	Huffman W.	Government/University	United States	All United States	All livestock
*1993	Mazzucato V.	Government	Africa	Niger	Other crops
1993	McKenney D.	Government	Multiple locations	Australia, Asia/Pacific	Forestry
1993	Norton G.	University	United States	U.S. state	All agriculture
1993	Norton G.	University	United States	U.S. state	All agriculture
*1993	Schwartz L.	Government	Africa	Senegal	Beans
*1993	Shih J.	Other	Asia/Pacific	Taiwan	Unspecified
*1993	Shih J.	Other	Asia/Pacific	Taiwan	Unspecified
1993a	Thirtle C.	Government	Africa	Zimbabwe	All agriculture
*1993b	Thirtle C.	Government	Africa	South Africa	All agriculture
*1993b	Thirtle C.	Government	Africa	South Africa	All agriculture
1994	Alston J.	University	United States	U.S. state	All agriculture
*1994	Alston J.	University	United States	U.S. state	All agriculture
*1994	Boughton D.	Government	Africa	Mali	Maize

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Extension	Implicit	Real	Average	Social	1	22.00	22.00
Both	Explicit	Real	Average	Social	2	84.80	90.90
Both	Explicit	Nominal	Average	Social	1	49.00	49.00
Research	Direct	Real	Marginal	Social	1	48.00	48.00
Research	Explicit	Nominal	Average	Social	1	52.00	52.00
Both	Explicit	Nominal	Average	Social	1	111.00	111.00
Research	Direct	Real	Marginal	Social	2	80.00	116.00
Both	Implicit	Nominal	Average	Social	2	25.00	40.00
Research	Implicit	Real	Average	Social	5	18.70	52.80
Both	Direct	Nominal	Marginal	Social	1	54.00	54.00
Research	Direct	Real	Marginal	Social	1	40.00	40.00
Both	Implicit	Real	Average	Social	3	15.00	16.00
Research	Implicit	Real	Average	Social	1	23.00	23.00
Research	Direct	Real	Marginal	Social	3	38.00	58.00
Research	Implicit	Nominal	Average	Social	1	23.51	23.51
Both	Explicit	Nominal	Average	Social	9	13.15	33.70
Extension	Direct	Nominal	Marginal	Social	4	86.00	136.00
Extension	Direct	Nominal	Marginal	Social	2	52.00	350.00
Research	Implicit	Real	Average	Social	3	22.00	27.00
Research	Implicit	Real	Average	Social	1	16.00	16.00
Research	Direct	Real	Marginal	Social	18	27.20	384.40
Both	Explicit	Real	Average	Social	4	−100.00	102.10
Both	Implicit	Real	Average	Social	4	−100.00	106.20
Research	Explicit	Real	Average	Social	2	96.90	106.20
Research	Implicit	Real	Average	Social	2	103.00	110.30
Extension	Direct	Real	Marginal	Social	1	20.10	20.10
Research	Direct	Real	Marginal	Social	3	40.60	73.50
Extension	Direct	Real	Marginal	Social	1	40.10	40.10
Research	Direct	Real	Marginal	Social	3	41.60	62.60
Both	Direct	Real	Marginal	Social	2	<0	
Research	Direct	Real	Marginal	Social	2	83.20	86.60
Both	Explicit	Nominal	Average	Social	1	10.00	10.00
Research	Explicit	Real	Average	Social	3	27.10	45.20
Extension	Direct	Real	Marginal	Social	1	37.00	37.00
Research	Direct	Real	Marginal	Social	1	58.00	58.00
Both	Implicit	Nominal	Average	Social	3	31.00	92.00
Both	Direct	Real	Marginal	Social	2	65.17	69.20
Research	Direct	Real	Marginal	Social	2	52.61	63.00
Both	Direct	Nominal	Marginal	Social	1	43.00	43.00
Both	Direct	Nominal	Marginal	Social	1	145.00	145.00
Research	Direct	Nominal	Marginal	Social	2	128.00	135.00
Both	Direct	Nominal	Average	Social	2	17.10	19.10
Research	Direct	Nominal	Average	Social	2	19.50	21.40
Both	Implicit	Nominal	Average	Social	10	38.00	135.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
*1994	Byerlee D.	Government	Africa	Africa	Wheat
*1994	Byerlee D.	Government	Asia/Pacific	South Asia	Wheat
*1994	Byerlee D.	Government	Latin America/Caribbean	Latin America/ Caribbean	Wheat
*1994	Byerlee D.	Government	Multiple locations	Africa, Asia/Pacific, Latin America/ Caribbean	Wheat
*1994	Byerlee D.	Government	West Asia, North Africa	West Asia, North Africa	Wheat
*1994	Byerlee D.	Government/International	Global	Global	Wheat
*1994	Byerlee D.	Government/International	Multiple locations	Mexico	Wheat
*1994	Cap E.	Government	Latin America/Caribbean	Argentina	Beef
*1994	Cap E.	Government	Latin America/Caribbean	Argentina	Dairy
*1994	Cap E.	Government	Latin America/Caribbean	Argentina	Maize
*1994	Cap E.	Government	Latin America/Caribbean	Argentina	Other crops
*1994	Cap E.	Government	Latin America/Caribbean	Argentina	Potato
*1994	Cap E.	Government	Latin America/Caribbean	Argentina	Wheat
1994	Davis J.	Other	Australia	Australia	Fruit, nut
1994	Davis J.	Other	Multiple locations	Australia, Asia/Pacific	Fruits, nuts
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Beans
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Dairy
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Fishery
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Fishery
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Fruit, nuts
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Fruit, nuts
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Groundnuts
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Maize
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Other crops
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Other crops
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Other tree
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Other tree
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Potato
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Potato
1994a	Evenson R.	Government	Asia/Pacific	Indonesia	Rice
*1994b	Evenson R.	Government	Latin America/Caribbean	Brazil	Beans
*1994b	Evenson R.	Government	Latin America/Caribbean	Brazil	Beans
*1994b	Evenson R.	Government	Latin America/Caribbean	Brazil	Maize
*1994b	Evenson R.	Government	Latin America/Caribbean	Brazil	Other crops
*1994b	Evenson R.	Government	Latin America/Caribbean	Brazil	Rice
*1994b	Evenson R.	Government	Latin America/Caribbean	Brazil	Wheat
*1994c	Evenson R.	Government/International	Multiple locations	Global	Rice
*1994a	Fearn M.	Government	Multiple locations	Australia, Asia/Pacific	Sheep, goats
*1994b	Fearn M.	Government/University	Multiple locations	Australia, Asia/Pacific	Fishery

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Explicit	Real	Average	Social	1	25.00	25.00
Research	Explicit	Real	Average	Social	1	94.00	94.00
Research	Explicit	Real	Average	Social	1	81.00	81.00
Research	Explicit	Real	Average	Social	1	50.00	50.00
Research	Explicit	Real	Average	Social	1	71.00	71.00
Research	Explicit	Real	Average	Social	1	54.00	54.00
Research	Explicit	Real	Average	Social	1	53.00	53.00
Both	Explicit	Real	Average	Social	1	73.67	73.67
Both	Explicit	Real	Average	Social	1	55.14	55.14
Both	Explicit	Real	Average	Social	1	77.05	77.05
Both	Explicit	Real	Average	Social	2	54.34	59.54
Both	Explicit	Real	Average	Social	1	68.99	68.99
Both	Explicit	Real	Average	Social	1	67.32	67.32
Research	Explicit	Real	Average	Social	3	21.00	38.00
Research	Explicit	Real	Average	Social	3	34.00	48.00
Research	Direct	Nominal	Marginal	Social	1	40.00	40.00
Research	Direct	Nominal	Marginal	Social	1	>100	
Research	Direct	Nominal	Marginal	Social	1	>100	
Research	Direct	Nominal	Marginal	Social	1	90.00	90.00
Research	Direct	Nominal	Marginal	Social	3	>100	
Research	Direct	Nominal	Marginal	Social	1	80.00	80.00
Research	Direct	Nominal	Marginal	Social	1	10.00	10.00
Research	Direct	Nominal	Marginal	Social	1	>100	
Research	Direct	Nominal	Marginal	Social	7	>0	
Research	Direct	Nominal	Marginal	Social	1	50.00	50.00
Research	Direct	Nominal	Marginal	Social	6	>100	
Research	Direct	Nominal	Marginal	Social	2	20.00	60.00
Research	Direct	Nominal	Marginal	Social	1	>100	
Research	Direct	Nominal	Marginal	Social	1	100.00	100.00
Research	Direct	Nominal	Marginal	Social	2	>100	
Research	Direct	Real	Marginal	Social	1	<0	
Research	Direct	Real	Marginal	Social	1	54.00	54.00
Research	Direct	Real	Marginal	Social	2	58.00	62.00
Research	Direct	Real	Marginal	Social	2	40.00	46.00
Research	Direct	Real	Marginal	Social	2	37.00	40.00
Research	Direct	Real	Marginal	Social	2	40.00	42.00
Research	Implicit	Real	Average	Social	2	255.00	285.00
Research	Implicit	Real	Average	Social	4	21.40	32.40
Research	Explicit	Real	Average	Social	3	17.00	24.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Subregion	Commodity[c]
*1994c	Fearn M.	Government/University	Multiple locations	Australia, Asia/Pacific	Fishery
*1994d	Fearn M.	Government/University	Multiple locations	Australia, Asia/Pacific	Maize
*1994d	Fearn M.	Government/University	Multiple locations	Australia, Asia/Pacific	Other crops
*1994	Garcia H.	Government	Latin America/Caribbean	Argentina	Other crops
*1994	Howard J.	Government	Africa	Zambia	Maize
*1994	Howard J.	Government	Africa	Zambia	Maize
*1994	Howard J.	Government	Africa	Zambia	Maize
*1994	Howard J.	Government	Africa	Zambia	Maize
*1994	Howard J.	Government	Africa	Zambia	Maize
*1994	Klein K.	Government	Canada	Canada	Beef
*1994	Kupfuma B.	Government	Africa	Zimbabwe	Maize
*1994a	Laker-Ojok R.	Government	Africa	Uganda	Groundnuts
*1994a	Laker-Ojok R.	Government	Africa	Uganda	Groundnuts
*1994a	Laker-Ojok R.	Government	Africa	Uganda	Sesame
*1994a	Laker-Ojok R.	Government	Africa	Uganda	Sesame
*1994b	Laker-Ojuk R.	Government	Africa	Uganda	Maize
*1994b	Laker-Ojuk R.	Government	Africa	Uganda	Maize
*1994b	Laker-Ojuk R.	Government	Africa	Uganda	Maize
*1994b	Laker-Ojuk R.	Government	Africa	Uganda	Other crops
*1994b	Laker-Ojuk R.	Government	Africa	Uganda	Other crops
*1994	Lubulwa G.	Other	Australia	Australia	Other tree
*1994a	Macagno L.	Government	Latin America/Caribbean	Argentina	Maize
*1994b	Macagno L.	Government	Latin America/Caribbean	Argentina	Other crops
*1994c	Macagno L.	Government	Latin America/Caribbean	Argentina	Wheat
*1994	Morris M.	Government	Asia/Pacific	Nepal	Wheat
*1994	Mullen J.	Government/University	Australia	Australia	Crops and livestock
*1994	Mullen J.	Government/University	Australia	Australia	Crops and livestock
*1994	Penna J.	Government	Latin America/Caribbean	Argentina	Potato
*1994	Sanders J.	Government	Africa	Ghana	Maize
*1994	Smale M.	Government	Africa	Malawi	Maize
*1994	Sterns J.	Government	Africa	Cameroun	Beans
*1994	Sterns J.	Government	Africa	Cameroun	Sorghum
*1994	Sterns J.	Government	Africa	Cameroun	Sorghum
*1995	Anandajayaskeram P.	Government	Africa	Namibia	Millet
*1995	Anandajayaskeram P.	Government	Africa	Zimbabwe	Sorghum
*1995	Araji A.	Other	United States	All United States	Potato
*1995	Araji A.	Other	United States	U.S. state	Potato
1995	Avila A.	Government	Latin America/Caribbean	Brazil	All crops
1995	Avila A.	Government	Latin America/Caribbean	Brazil	All crops
1995	Avila A.	Government	Latin America/Caribbean	Brazil	All livestock
1995	Avila A.	Government	Latin America/Caribbean	Brazil	All livestock

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Explicit	Real	Average	Social	5	19.00	34.00
Research	Explicit	Real	Average	Social	6	24.60	59.60
Research	Explicit	Real	Average	Social	6	26.00	63.50
Both	Explicit	Real	Average	Social	3	40.20	50.10
Both	Explicit	Real	Average	Social	1	<0	
Both	Implicit	Real	Average	Social	1	<0	
Both	Explicit	Real	Average	Social	3	42.10	105.80
Both	Implicit	Real	Average	Social	1	49.30	49.30
Research	Explicit	Real	Average	Social	2	113.90	116.60
Research	Explicit	Nominal	Average	Social	2	152.00	185.00
Both	Explicit	Real	Average	Social	4	43.50	46.50
Both	Implicit	Real	Average	Social	5	–3.40	37.10
Research	Implicit	Real	Average	Social	4	14.30	44.40
Both	Implicit	Real	Average	Social	6	–12.30	43.60
Research	Implicit	Real	Average	Social	4	22.10	49.00
Both	Explicit	Real	Average	Social	3	–56.60	35.60
Both	Implicit	Real	Average	Social	6	–33.40	33.20
Research	Implicit	Real	Average	Social	3	–6.90	35.10
Both	Implicit	Real	Average	Social	6	–14.30	35.80
Research	Implicit	Real	Average	Social	2	–7.40	3.20
Research	Explicit	Real	Average	Social	2	13.00	14.00
Both	Explicit	Real	Average	Social	1	47.50	47.50
Both	Explicit	Real	Average	Social	1	34.30	34.30
Both	Explicit	Real	Average	Social	1	32.00	32.00
Research	Implicit	Real	Average	Social	6	40.00	84.00
Both	Direct	Real	Marginal	Social	8	42.00	430.00
Research	Direct	Real	Marginal	Social	8	50.00	562.00
Both	Explicit	Nominal	Average	Social	3	52.60	61.23
Both	Explicit	Nominal	Average	Social	1	74.00	74.00
Research	Implicit	Real	Average	Social	4	4.00	63.00
Both	Implicit	Nominal	Average	Social	2	11.40	15.50
Both	Implicit	Nominal	Average	Social	2	–2.30	0.90
Research	Implicit	Nominal	Average	Social	1	7.70	7.70
Both	Explicit	Nominal	Average	Social	4	4.25	20.13
Both	Explicit	Nominal	Average	Social	8	21.80	27.60
Research	Direct	Nominal	Marginal	Social	1	79.02	79.02
Research	Direct	Nominal	Marginal	Social	6	41.26	153.71
Extension	Direct	Real	Marginal	Social	1	33.00	33.00
Research	Direct	Real	Marginal	Social	3	29.00	75.00
Extension	Direct	Real	Marginal	Social	1	23.00	23.00
Research	Direct	Real	Marginal	Social	3	25.00	90.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Location of research performer: Subregion	Commodity[c]
1995	Avila A.	Government	Latin America/Caribbean	Brazil	Crops and livestock
1995	Avila A.	Government	Latin America/Caribbean	Brazil	Crops and livestock
*1995	Aw-Hassan A.	Government	West Asia, North Africa	Egypt	Wheat
*1995	Byerlee D.	Government	Africa	Unknown	Wheat
*1995	Byerlee D.	Government	Asia/Pacific	South	Wheat
*1995	Byerlee D.	Government	Latin America/Caribbean	Unknown	Wheat
*1995	Byerlee D.	Government	West Asia, North Africa	Unknown	Wheat
*1995	Byerlee D.	Government/International	Global	Global	Wheat
*1995	Byerlee D.	Government/International	Global	Global	Wheat
*1995	Collins M.	Government	Asia/Pacific	Pakistan	Wheat
*1995	Collins M.	Government	Asia/Pacific	Pakistan	Wheat
*1995	Fuglie K.	Government/International	Multiple locations	West Asia, North Africa, Latin America/Caribbean	Potato
*1995	Joshi P.	Government/International	Asia/Pacific	India	Groundnuts
*1995a	Lubulwa G.	Government	Australia	Australia	Forestry
*1995b	Lubulwa G.	Government	Australia	Australia	Other crops
*1995c	Lubulwa G.	Government	Multiple locations	Australia, Asia/Pacific	Forestry
*1995d	Lubulwa G.	Government	Multiple locations	Australia/Kenya	Crops and livestock
*1995e	Lubulwa G.	Government/International	Multiple locations	Australia, Asia/Pacific	Cassava
1995	Mullen J.	Government/University	Australia	Australia	Crops and livestock
1995	Mullen J.	Government/University	Australia	Australia	Crops and livestock
*1995	Ouedraogo S.	Government	Africa	Burkina Faso	Maize
*1995	Robinson S.	Government	Australia	Australia	Pasture
*1995	Robinson S.	Government	Australia	Australia	Sheep, goats
*1995	Seck P.	Government	Africa	Senegal	Other crops
1995	Thirtle C.	Other	Europe	Belgium, Luxembourg	All agriculture
1995	Thirtle C.	Other	Europe	Denmark	All agriculture
1995	Thirtle C.	Other	Europe	EC-10	All agriculture
1995	Thirtle C.	Other	Europe	France	All agriculture
1995	Thirtle C.	Other	Europe	Germany	All agriculture
1995	Thirtle C.	Other	Europe	Greece	All agriculture
1995	Thirtle C.	Other	Europe	Ireland	All agriculture
1995	Thirtle C.	Other	Europe	Italy	All agriculture
1995	Thirtle C.	Other	Europe	Netherlands	All agriculture
1995	Thirtle C.	Other	Europe	United Kingdom	All agriculture
*1995	Tré J.-P.	International	Africa	Sierra Leone	Rice
*1995	White F.	Government/University	United States	All United States	All agriculture

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Extension	Direct	Real	Marginal	Social	1	19.00	19.00
Research	Direct	Real	Marginal	Social	3	19.00	56.00
Both	Implicit	Real	Average	Social	6	28.00	38.00
Research	Explicit	Nominal	Average	Social	1	23.00	23.00
Research	Explicit	Nominal	Average	Social	1	91.00	91.00
Research	Explicit	Nominal	Average	Social	1	82.00	82.00
Research	Explicit	Nominal	Average	Social	1	71.00	71.00
Research	Explicit	Nominal	Average	Social	1	52.00	52.00
Research	Explicit	Real	Average	Social	2	37.00	48.00
Both	Explicit	Real	Average	Social	3	28.00	51.00
Research	Explicit	Real	Average	Social	3	60.00	71.00
Both	Explicit	Real	Average	Social	3	45.00	74.00
Research	Explicit	Nominal	Average	Social	4	9.94	37.88
Research	Explicit	Real	Average	Social	2	7.00	56.97
Research	Explicit	Real	Average	Social	1	14.46	14.46
Research	Explicit	Real	Average	Social	3	0.00	26.80
Research	Explicit	Nominal	Average	Social	1	20.43	20.43
Research	Explicit	Real	Average	Social	1	12.76	12.76
Extension	Direct	Real	Marginal	Social	2	40.00	45.00
Research	Direct	Real	Marginal	Social	2	17.00	30.00
Both	Explicit	Real	Average	Social	1	78.10	78.10
Research	Implicit	Real	Average	Social	1	22.00	22.00
Research	Implicit	Real	Average	Social	3	20.00	69.00
Both	Explicit	Nominal	Average	Social	3	32.90	37.00
Research	Direct	Real	Marginal	Social	2	0.00	107.00
Research	Direct	Real	Marginal	Social	2	220.00	464.00
Research	Direct	Real	Marginal	Social	1	32.00	32.00
Research	Direct	Real	Marginal	Social	2	277.00	316.00
Research	Direct	Real	Marginal	Social	2	48.00	57.00
Research	Direct	Real	Marginal	Social	2	564.00	1,219.00
Research	Direct	Real	Marginal	Social	2	0.00	177.00
Research	Direct	Real	Marginal	Social	2	85.00	115.00
Research	Direct	Real	Marginal	Social	2	59.00	102.00
Research	Direct	Real	Marginal	Social	2	44.00	99.00
Research	Explicit	Real	Average	Social	4	17.92	21.40
Research	Direct	Real	Average	Social	1	40.40	40.40

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Subregion	Commodity[c]
1995	Yee J.	Government/University	United States	All United States	All agriculture
*1996	Aghib A.	Government	Africa	Niger	Sorghum
*1996	Akgungor S.	Government	Africa	Kenya	Wheat
*1996	Alston J.	Other	United States	All United States	All agriculture
*1996	Alvarez P.	Government/International	Latin America/Caribbean	Dominican Republic	Potato
1996	Arnade C.	Government/University	Africa	South Africa	All agriculture
1996	Arnade C.	Government/University	Africa	South Africa	All agriculture
*1996	Bantilan M.	International	Asia/Pacific	India	Pigeon, chickpea
*1996	Bofu S.	Government	Asia/Pacific	China	Potato
*1996	Bofu S.	Government/International	Global	Global	Potato
*1996	Chilver A.	Government/International	Multiple locations	India, Peru	Potato
*1996	Chisi M.	Government	Africa	Zambia	Sorghum
1996	Evenson R.	Private	United States	All United States	All crops
1996	Evenson R.	Private	United States	All United States	All livestock
1996	Evenson R.	Private	United States	All United States	Crops and livestock
1996	Evenson R.	Government/University	United States	All United States	All crops
1996	Evenson R.	Government/University	United States	All United States	All crops
1996	Evenson R.	Government/University	United States	All United States	All livestock
1996	Evenson R.	Government/University	United States	All United States	All livestock
1996	Evenson R.	Government/University	United States	All United States	All livestock
1996	Evenson R.	Government/University	United States	All United States	Crops and livestock
*1996	Fonseca C.	Government/International	LAC	Peru	Potato
1996	Gopinath M.	Other	United States	All United States	All agriculture
1996	Gopinath M.	Other	United States	All United States	All agriculture
*1996	Hossain M.	Government	Asia/Pacific	Bangladesh	Rice
*1996	Howard J.	Government	Africa	Zambia	Maize
*1996	Howard J.	Government	Africa	Zambia	Maize
1996	Karanja D.	Government	Africa	Kenya	Maize
*1996	Khatana V.	Government/International	Global	Global	Potato
1996a	Khatri Y.	Government	Africa	South Africa	Crops and livestock
1996b	Khatri Y.	Other	Europe	United Kingdom	Crops and livestock
*1996	Klein K.	Government	Canada	Canada	Wheat
*1996	Kuroda Y.	Other	Asia/Pacific	Taiwan	Rice
*1996	Lubulwa G.	Government/University	Multiple locations	Australia, Asia/Pacific	Sheep, goats
*1996	Makki S.	Government/Private	United States	All United States	All agriculture
*1996	Makki S.	Government/Private	United States	All United States	All agriculture
*1996	Mullen J.	Government/University	Australia	Australia	Crops and livestock
*1996	Njomaha C.	Government	Africa	Cameroun	Sorghum
*1996	Ortiz O.	Government/International	Latin America/Caribbean	Peru	Potato

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Research	Direct	Real	Marginal	Social	3	40.00	46.00
Both	Explicit	Real	Average	Social	6	45.00	66.40
Research	Direct	Real	Marginal	Social	1	14.00	14.00
Both	Direct	Real	Marginal	Social	16	−1.00	260.00
Both	Implicit	Real	Average	Social	1	27.00	27.00
Research	Direct	Nominal	Average	Social	1	170.00	170.00
Research	Direct	Real	Marginal	Social	2	44.00	58.00
Research	Explicit	Nominal	Average	Social	1	64.80	64.80
Both	Implicit	Real	Average	Social	1	102.00	102.00
Both	Implicit	Real	Average	Social	1	65.00	65.00
Research	Implicit	Nominal	Average	Social	1	22.00	22.00
Both	Explicit	Nominal	Average	Social	17	10.22	25.18
Research	Direct	Real	Marginal	Social	1	90.00	90.00
Research	Direct	Real	Marginal	Social	2	57.00	71.00
Research	Direct	Real	Marginal	Social	2	71.00	83.00
Extension	Direct	Real	Marginal	Social	2	101.00	138.00
Research	Direct	Real	Marginal	Social	3	40.00	57.00
Research	Direct	Real	Marginal	Social	1	<0	
Extension	Direct	Real	Marginal	Social	2	81.00	99.00
Research	Direct	Real	Marginal	Social	3	11.00	83.00
Research	Direct	Real	Marginal	Social	4	43.00	67.00
Research	Implicit	Nominal	Average	Social	1	26.00	26.00
Research	Direct	Real	Marginal	Private	12	8.90	40.40
Research	Direct	Real	Marginal	Social	12	12.70	52.80
Both	Explicit	Real	Average	Social	2	16.60	36.20
Both	Implicit	Nominal	Average	Social	1	<0	
Both	Implicit	Nominal	Average	Social	7	42.10	96.00
Research	Direct	Real	Marginal	Social	4	39.00	60.80
Research	Implicit	Real	Average	Social	4	10.00	33.20
Research	Direct	Real	Marginal	Social	1	44.25	44.25
Research	Direct	Real	Marginal	Social	3	17.32	18.56
Research	Explicit	Real	Average	Social	1	32.80	32.80
Both	Direct	Real	Marginal	Social	1	45.00	45.00
Research	Implicit	Real	Average	Social	1	24.00	24.00
Both	Direct	Real	Marginal	Social	1	27.00	27.00
Research	Direct	Real	Marginal	Social	1	6.00	6.00
Both	Direct	Real	Marginal	Social	3	18.00	39.00
Both	Explicit	Nominal	Average	Social	9	10.90	122.50
Both	Implicit	Real	Average	Social	1	30.00	30.00

(continued)

Appendix—Continued

Year published[a]	First author	Research performer[b]	Location of research performer: Region	Subregion	Commodity[c]
1996	Ouedraogo S.	Government	Africa	Burkina Faso	Other crops
*1996	Rueda J.	Government	Africa	Rwanda Burundi	Potato
*1996	Uyen N.	Government	Asia/Pacific	Vietnam	Potato
*1996	Yallah N.	Government	Africa	Chad	Other crops
*1996	Yapi A.	International	Africa	Mali	Millet
*1996	Yapi A.	International	Africa	Mali	Sorghum
*1997	Azzam A.	Government	West Asia, North Africa	Morocco	Wheat
*1997	Barkley A.	University	United States	U.S. state	Wheat
*1997	Berlin R.	Government	Africa	Mali	Millet
*1997	Bindlish V.	Government	Africa	Kenya	All crops
*1997	Bindish V.	Government	Africa	Kenya	All crops
*1997	Chilver A.	International	West Asia, North Africa	Egypt	Potato
*1997	Edwin J.	Government	Africa	Sierra Leone	Rice
*1997	Ouedraogo S.	Government	Africa	Burkina Faso	Other crops
*1997	Seidi S.	Government	Africa	Guinea Buissau	Rice
*1998	Alston J.	Other	United States	All United States	All agriculture

Source: Compiled by the authors from the listing that follows.
Note: n.a. indicates not available.
[a] An asterisk indicates a publication that included observations that were used in the regression analysis.
[b] "Other" includes the following research performers; NGOs, foundations, CARDI (Caribbean Agricultural Research and Development Institute), farmers, jointly international institutes and universities, jointly private sector and other, jointly university and other, and unspecified affiliations.
[c] "All agriculture" typically involves studies that assessed the returns to R&D that spanned the entire agriculture sector. "Crops and livestock" includes studies that involved multiple crop and livestock commodities. "Other crops, "Other livestock," and "Other tree" refer to studies that reported rates of return for specific crops, livestock products, and tree crops not specifically identified elsewhere in this category.
[d] "Explicit" refers to studies wherein the benefits were calculated using an explicit economic surplus model, "Implicit" refers to studies in which the surplus model was left implicit, and "Direct" includes studies that calculated the benefits using the estimates obtained directly from an econometric model.

Rate of return type	Benefit calculation type[d]	Real or nominal	Marginal or average	Private or social	Number of observations	Minimum value	Maximum value
					(count)	(percentage)	
Extension	Explicit	Real	Average	Social	1	7.00	7.00
Both	Implicit	Nominal	Average	Social	1	84.00	84.00
Research	Implicit	Real	Average	Social	1	70.00	70.00
Both		Nominal	Average	Social	1	188.00	188.00
Both	Explicit	Real	Average	Social	1	69.98	69.98
Both	Explicit	Real	Average	Social	1	50.00	50.00
Research	Implicit	Nominal	Average	Social	1	39.00	39.00
Research	Explicit	Real	Average	Social	1	39.00	39.00
Both	Implicit	Real	Average	Social	2	30.61	37.64
Extension	Direct	Nominal	Marginal	Social	1	>100	
Extension	Direct	Nominal	Marginal	Social	1	28.00	28.00
Research	Implicit	Nominal	Average	Social	1	28.00	28.00
Research	Explicit	Real	Average	Social	1	34.10	34.10
Both	Explicit	Real	Average	Social	1	52.71	52.71
Both	Explicit	Nominal	Average	Social	1	26.00	26.00
Both	Direct	Real	Marginal	Social	16	3.90	147.00

References to Appendix

Abidogun, A. 1978. Cocoa research in Nigeria: An *ex-post* investment analysis. *Nigerian Journal of Economics and Social Studies* 20 (March): 21–35.

Aghib, A. J. 1996. The economic impact assessment of the World Vision International–Purdue University *Striga*-resistant sorghum initiatives. Purdue University, West Lafayette, Ind. U.S.A. Mimeo.

Ahmed, M. M., W. A. Masters, and J. H. Sanders. 1993. Returns from research in distorted economies: Hybrid sorghum in Sudan. Purdue University, West Lafayette, Ind., U.S.A. (25 February). Mimeo.

Akgungor, S., D. M. Makanda, J. F. Oehmke, R. J. Myers, and Y. C. Choe. 1996. Dynamic analysis of Kenyan wheat research and rate of return. Contributed paper for the Conference on Global Agricultural Science Policy for the 21st Century, 26–28 August, Melbourne.

Akino, M., and Y. Hayami. 1975. Efficiency and equity in public research: Rice breeding in Japan's economic development. *American Journal of Agricultural Economics* 57 (February): 1–10.

Alston, J. M., B. J. Craig, and P. G. Pardey. 1996. Research lags and research returns. Proceedings of the Conference on Global Agricultural Science Policy for the 21st Century, 26–28 August, Melbourne.

———. 1998. Dynamics in the creation and depreciation of knowledge, and the returns to agricultural research. EPTD Discussion Paper No. 56. International Food Policy Research Institute, Washington, D.C.

Alston, J. M., P. G. Pardey, and H. O. Carter, eds. 1994. *Valuing UC agricultural research and extension.* Agricultural Issues Center Publication No. VR-1. Davis: University of California, Agricultural Issues Center (March).

Alvarez, P., V. Escarraman, E. Gomez, A. Villar, R. Jimenez, O. Ortiz, J. Alcazar, and M. Palacios. 1996. Economic impact of managing sweet potato weevil (*Cylas formicarius*) with sex pheromones in the Dominican Republic. In *Case Studies of the Economic Impact of CIP-Related Technology,* ed. T. S. Walker and C. C. Crissman, pp. 83–94. Lima, Peru: International Potato Center.

Ambrosi, I., and E. R. Da Cruz. 1986. Taxas de retorno dos recursos aplicados em pesquisa no Centro Nacional de Pesquisa de Trigo, Embrapa. *Revista de Economia Rural* 24 (April/June): 195–209.

Anandajayasekeram, P., D. R. Martella, J. H. Sanders, and B. Kuffuma. 1995. Report on the impact assessment of the SADC/ICRISAT Sorghum and Millet Improvement Program. Southern African Development Coordination Conference (SADCC) and Southern African Center for Cooperation in Agricultural Research (SACCAR), Gaborone, Botswana. Mimeo.

Antony, G. 1990a. *Appraisal of the expected economic effects of research projects planned or undertaken at the Cocoa and Coconut Research Institute.* Research Bulletin No. 45. Konedobu, Papua New Guinea: Department of Agriculture and Livestock, Government of Papua New Guinea (February).

———. 1990b. *Appraisal of the expected economic effects of research undertaken in oil palm in Papua New Guinea.* Research Bulletin No. 47. Konedobu, Papua New Guinea: Department of Agriculture and Livestock, Government of Papua New Guinea (February).

———. 1990c. *Appraisal of the expected economic effects of research projects planned or undertaken at the Coffee Research Institute.* In cooperation with the University of New England, Armidale, and Australian Centre for International Agricultural Research (ACIAR). Research Bulletin No. 46. Konedobu, Papua New Guinea: Department of Agriculture and Livestock, Government of Papua New Guinea (February).

Antony, G., and G. Y. Kauzi. 1988. Returns to cocoa research 1965 to 1980 in Papua New Guinea (and returns to research on insect pollination of oil palm in Papua New Guinea). Paper presented at the annual conference of the Australian Agricultural Economics Society, 9–11 February, La Trobe University, Melbourne.

Araji, A. A. 1981. The economic impact of investment in integrated pest management. In *Evaluation of agricultural research,* ed. G. W. Norton et al., pp. 121–139. Minneapolis, Minn., U.S.A.: Minnesota Agricultural Experiment Station, University of Minnesota (April).

———. 1983. A multimarket equilibrium approach to evaluating the impact of a technological change. University of Idaho, Moscow, U.S.A. Mimeo.

———. 1989. Return to public investment in wheat research in the Western United States. *Canadian Journal of Agricultural Economics* 37: 467–479.

———. 1990a. The functions, focus, and productivity of the State Agricultural Experiment Stations in the United States. *Agribusiness* 6 (November): 633–642.

———. 1990b. *The benefits of investments in the University of Idaho College of Agriculture research and extension programs.* Bulletin No. 720. Moscow, Idaho, U.S.A.: University of Idaho (December).

Araji, A. A., R. J. Sim, and B. L. Gardner. 1978. Returns to agricultural research and extension programs: Ex-ante approach. *American Journal of Agricultural Economics* 60 (December): 964–968.

Araji, A. A., and F. C. White. 1990. *The benefit of research to producers and consumers of western wheat.* Bulletin No. 717. Moscow, Idaho, U.S.A.: University of Idaho (September).

Araji, A. A., F. C. White, and J. F. Guenthner. 1995. Spillovers and the returns to agricultural research for potatoes. *Journal of Agricultural and Resource Economics* 20 (December): 263–276.

Arnade, C., Y. J. Khatri, D. Schimmelpfennig, C. G. Thirtle, and J. van Zyl. 1996. Short and long-run returns to agricultural R&D in South Africa, or Will the real rate of return please stand up? Contributed paper for the Conference on Global Agricultural Science Policy for the 21st Century, 26–28 August, Melbourne.

Avila, A. F. D. 1981. Evaluation de la recherche agronomique au Brésil: Le cas de la recherche rizicole de l'IRGA ou Rio Grande du Sol. Ph.D. diss., Université de Montpellier, Montpellier, France.

Avila, A. F. D., and R. E. Evenson. 1995. Total factor productivity growth in Brazilian agriculture and the role of agricultural research. Congresso Brasileiro de Economia e Sociologia Rural, Brasilia. Mimeo.

Avila, A. F. D., L. J. M. Irias, and R. F. V. Veloso. 1984. *Avaliacao dos impactos socioeconomicos do Projecto PROCENSUL I.* Embrapa-DDM Documentos No. 16. Brasilia: Empresa Brasileira de Pesquisa Agropecuária (Embrapa).

Aw-Hassan, A., A. Ghanem, A. A. Ali, M. Mansour, and M. B. Sohl. 1995. Economic returns from improved wheat technology in Upper Egypt. ICARDA Social Science Papers No. 1. Aleppo, Syria: International Center for Agricultural Research in the Dry Areas.

Ayer, H. W. 1970. The costs, returns and effects of agricultural research in Sâo Paulo, Brazil. Ph.D. diss., Purdue University, West Lafayette, Ind., U.S.A.

Ayer, H. W., and G. E. Schuh. 1972. Social rates of return and other aspects of agricultural research: The case of cotton research in São Paulo, Brazil. *American Journal of Agricultural Economics* 54 (November): 557–569.

Ayres, C. H. S. 1985. The contribution of agricultural research to soybean productivity in Brazil. Ph.D. diss., University of Minnesota, St. Paul, U.S.A.

Azam, Q. T., E. A. Bloom, and R. E. Evenson. 1991. *Agricultural research productivity in Pakistan.* Economic Growth Center Discussion Paper No. 644. New Haven, Conn., U.S.A.: Yale University (May).

Azzam, A., S. Azzam, S. Lhaloui, A. Amri, M. El Bouhssini, and M. Moussaoui. 1997. Economic returns to research in Hessian fly resistant bread-wheat varieties in Morocco. *Journal of Economic Entomology* 90 (February): 1–5.

Bantilan, M. C. S., and P. K. Joshi. 1996. Returns to research and diffusion investments on wilt resistance in pigeonpea. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Andhra Pradesh, India. Mimeo.

Bare, B. B., and R. Loveless. 1985. An overview of the Regional Forest Nutrition Research Project. In *Forestry research evaluation: Current progress, future directions. Proceedings of the Forestry Research Evaluation Workshop,* ed. C. D. Risbrudt and P. J. Jakes, pp. 52–61. General Technical Report NC-104. St. Paul, Minn., U.S.A.: USDA Forest Service, North Central Forest Experiment Station.

Barker, R., and R. W. Herdt. 1982. Setting priorities for rice research in Asia. In *Science, politics, and the agricultural revolution in Asia,* ed. R. S. Anderson et al., pp. 427–461. Boulder, Colo., U.S.A.: Westview Press for the American Association for the Advancement of Science.

Barkley, A. P. 1997. Kansas wheat breeding: An economic analysis. Selected paper presented at the Western Agricultural Economics Association Annual Meeting, 15 July, Sparks, Nev., U.S.A.

Barletta, N. A. 1971. Costs and social benefits of agricultural research in Mexico. Ph.D. diss., University of Chicago, Chicago, U.S.A.

Bengston, D. N. 1985. Aggregate returns to lumber and wood products research: An index number approach. In *Forestry research evaluation: Current progress, future directions. Proceedings of the Forestry Research Evaluation Workshop,* ed. C. D. Risbrudt and P. J. Jakes, pp. 62–68. General Technical Report NC-104. St.

Paul, Minn., U.S.A.: USDA Forest Service, North Central Forest Experiment Station.

Berlin, R. 1997. Impact de la recherche agronomique: Le cas de la région de Segou, Mali. Swiss Federal Institute of Technology, Lausanne (April). Mimeo.

Bindlish, V., and R. E. Evenson. 1993b. *Evaluation of the Performance of T&V Extension in Kenya.* World Bank Technical Paper No. 208. Africa Technical Department Series. Washington, D.C.: World Bank (October).

———. 1997. The impact of T&V extension in Africa: The experience of Kenya and Burkina Faso. *World Bank Research Observer* 12 (August): 183–201.

Bindlish, V., R. E. Evenson, and M. Gbetibouo. 1993a. *Evaluation of T&V-based extension in Burkina Faso.* World Bank Technical Paper No. 226. Africa Technical Department Series. Washington, D.C.: World Bank (November).

Blakeslee, L., and R. Sargent. 1982. Economic impacts of public research and extension related to wheat production in Washington. XB0929. Agricultural Research Center, Washington State University, Pullman, Washington, U.S.A. Mimeo.

Bofu, S., T. Weiming, W. Jimin, W. Chunlin, Y. Zhengui, W. Shengwu, and M. Huarte. 1996. Economic impact of CIP-24 in China. In *Case studies of the economic impact of CIP-related technology,* ed. T. S. Walker and C. C. Crissman, pp. 31–49. Lima, Peru: International Potato Center.

Boughton, D., and B. H. de Frahan. 1994. *Agricultural research impact assessment: The case of maize technology adoption in southern Mali.* MSU International Development Working Paper No. 41. East Lansing, Mich., U.S.A.: Michigan State University, Department of Agricultural Economics, Department of Economics.

Boyle, G. E. 1986. An exploratory assessment of the returns to agricultural research in Ireland 1963–1983. *Irish Journal of Agricultural Economics and Rural Sociology* 11: 57–71.

Braha, H., and L. G. Tweeten. 1986. *Evaluating past and prospective future payoffs from public investments to increase agricultural productivity.* Technical Bulletin No. T-163. Stillwater, Okla., U.S.A.: Agricultural Experiment Station, Oklahoma State University (September).

Bredahl, M. E., and W. L. Peterson. 1976. The productivity and allocation of research: U.S. Agricultural Experiment Stations. *American Journal of Agricultural Economics* 58 (November): 684–692.

Brennan, J. P. 1989. An analysis of the economic potential of some innovations in a wheat breeding program. *Australian Journal of Agricultural Economics* 33 (April): 48–55.

Brennan, J. P., and L. O'Brien. 1991. An economic investigation of early-generation quality testing in a wheat breeding program. *Plant Breeding* 106 (February): 132–140.

Brinkman, G. L., and B. E. Prentice. 1985. Returns to a provincial economy from investments in agricultural research: The case of Ontario. In *Economics of agricultural research in Canada,* ed. K. K. Klein and W. H. Furtan, pp. 115–141. Calgary, Alberta, Canada: University of Calgary Press.

Byerlee, D. 1993. Technical change and returns to wheat breeding research in Pakistan's Punjab in the post–Green Revolution period. *Pakistan Development Review* 32 (Spring): 69–86.

Byerlee, D., and G. Traxler. 1994. Economic returns to national and international wheat improvement research in the post–Green Revolution period. International Center for the Improvement of Maize and Wheat (CIMMYT), Mexico City (5 August). Mimeo.

———. 1995. National and international wheat improvement research in the post–Green Revolution period: Evolution and impacts. *American Journal of Agricultural Economics* 77 (May): 268–278.

Cap, E. J., and O. A. Miranda. 1994. Analisis *ex-ante* de impactos de la investigación agrícola en la Argentina para siete rubros productivos en escenarios alternativos. In *La investigación agrícola en la Argentina: Impactos y necesidades de inversión,* ed. F. M. Cirio and A. J. P. Castronovo, pp. 299–316. Buenos Aires: Instituto Nacional de Tecnología Agropecuaria.

Chamala, S., V. Karan, K. V. Raman, and A. U. Gadewar. 1991. *Nutritional disorders of grain sorghum.* Economic Assessment Series No. 10. Canberra: Australian Centre for International Agricultural Research.

Chavas, J.-P., and T. L. Cox. 1991. A nonparametric analysis of the influence of research on agricultural productivity. Staff Paper No. 362. Department of Agricultural Economics, University of Wisconsin, Madison (March).

———. 1992. A nonparametric analysis of the influence of research on agricultural productivity. *American Journal of Agricultural Economics* 74 (August): 583–591.

Chilver, A., R. El-Bedewy, and A. Rizk. 1997. True potato seed: Research, diffusion, and outcomes in Egypt. International Potato Center, Lima, Peru. Mimeo.

Chilver, A., T. Walker, V. S. Khatana, H. Fano, R. Suherman, and A. Risk. 1996. On-farm profitability of True Potato Seed (TPS) utilization technologies. Working Paper 1993-3, Social Sciences Department. Lima, Peru: International Potato Center.

Chisi, M., P. Anandajayasekeram, D. R. Martella, M. M. Ahmed, and M. Mwape. 1996. Impact assessment of sorghum research in Zambia, 1983–2010. Southern African Center for Cooperation in Agricultural Research, Gaborone, Botswana (September). Mimeo.

Chudleigh, P. D. 1991a. *Tick-borne disease control in cattle.* Economic Assessment Series No. 5. Canberra: Australian Centre for International Agricultural Research.

———. 1991b. *Integrated use of insecticides in grain storages in the humid tropics.* Economic Assessment Series No. 9. Canberra: Australian Centre for International Agricultural Research.

———. 1991c. *Breeding and quality analysis of canola (rapeseed).* Economic Assessment Series No. 6. Canberra: Australian Centre for International Agricultural Research.

Cline, P. L. 1975. Sources of productivity change in United States agriculture. Ph.D. diss., Oklahoma State University, Stillwater, Okla., U.S.A. (May).

Cline, P. L., and Y. C. Lu. 1976. Efficiency aspects of the spatial allocation of public sector agricultural research and extension in the United States. *Regional Science Perspectives* 6: 1–16.

Coffey, J. D., and G. W. Norton. 1982. *Return on investment in agricultural research and education in Virginia.* Information Series No. 82-1. Blacksburg, Va., U.S.A.: Virginia Polytechnic Institute and State University (July).

Collins, M. I. 1995. The economics of productivity maintenance research: A case study of wheat leaf rust resistance breeding in Pakistan. Ph.D. diss., University of Minnesota, St. Paul, U.S.A. (May).

Cordomi, M. L. 1989. Rates of return on agricultural research in expenditures in Argentina. In *Government intervention in agriculture: Cause and effect,* ed. B. L. Greenshields and M. A. Bellamy, pp. 95–101. Aldershot, U.K.: Dartmouth.

Da Cruz, E. R., and A. F. D. Avila. 1985. *Retorno dos investimentos da Embrapa em pequisa na area de abrangencia do Projecto BIRD I.* Embrapa Departamento de

Estudos e Pesquisas Documentos No. 19. Brasilia: Empresa Brasileira de Pesquisa Agropecuária (Embrapa).

———. 1992. Impactos económicos de la cooperación tecnologíca entre los países Andinos. *Investigación Agraria Económia* 7 (2): 283–289.

Da Cruz, E. R., V. Palma, and A. F. D. Avila. 1982. *Rates of return on Embrapa's investments: Total investment and physical capital.* Embrapa-DDM Documentos 1 No. 1. Brasilia: Empresa Brasileira de Pesquisa Agropecuária (Embrapa).

Da Silva, M. C., I. Agostini, L. C. R. Echeverría, C. L. Kreuz, R. de Nadal, and N. Cortina. 1986. *Análise dos beneficíos da pesquisa agropecuária em Santa Catarina: 10 anos de EMPASC.* EMPASC Documentos No. 74. Florianópolis, Brazil: Empresa Catarinense de Pesquisa Agropecuaria.

Davis, J. S. 1979. Stability of the research production coefficient for U.S. agriculture. Ph.D. diss., University of Minnesota, St. Paul, U.S.A. (December).

Davis, J. S., and A. S. G. Lubulwa. 1994. Evaluation of postharvest research: Results for an application to tropical fruit research projects and some further methodological issues. Contributed paper at the 38th Australian Agricultural Economics Society Conference, Victoria University, 8–10 February, Wellington, New Zealand.

Deininger, K. W. 1993. Technical change, human capital, and spillovers in U.S. agriculture, 1949–1985: An empirical analysis. Ph.D. diss., University of Minnesota, St. Paul, U.S.A. (June).

Dey, M. M., and R. E. Evenson. 1991. The economic impact of rice research in Bangladesh. Report for the Bangladesh Rice Research Institute and International Rice Research Institute (September). Mimeo.

Doeleman, J. A. 1990a. *Biological control of Salvinia.* Economic Assessment Series No. 1. Canberra: Australian Centre for International Agricultural Research.

———. 1990b. *Benefits and costs of entomopathogenic nematodes: Two biological control applications in China.* Economic Assessment Series No. 4. Canberra: Australian Centre for International Agricultural Research.

Doyle, C. J., and M. S. Ridout. 1985. The impact of scientific research on U.K. agricultural productivity. *Research Policy* 14 (April): 109–116.

Duncan, R. C. 1972. Evaluating returns to research in pasture improvement. *Australian Journal of Agricultural Economics* 16 (December): 153–168.

Dyer, P. T., and G. M. Scobie. 1984b. *The payoff to investment in agroforestry research: A preliminary report.* Discussion Paper No. 4/84. Hamilton, New Zealand: Ruakura Agricultural Research Centre (April).

Dyer, P. T., G. M. Scobie, and S. R. Davis. 1984a. *The payoff to investment in a recombinant DNA research facility at Ruakura: A Monte Carlo simulation study.* Discussion Paper No. 1/84. Hamilton, New Zealand: Ruakura Agricultural Research Centre (February).

Easter, K. W., and G. W. Norton. 1977. Potential returns from increased research budgets for the land-grant universities. *Agricultural Economics Research* 29 (October): 127–133.

Echeverría, R. G., G. Ferreira, and M. Dabezies. 1989. *Returns to investments in the generation and transfer of rice technology in Uruguay.* Working Paper No. 30. The Hague: International Service for National Agricultural Research (November).

Edwin, J., and W. A. Masters. 1997. Returns to rice technology development in Sierra Leone. Department of Agricultural Economics, Purdue University, West Lafayette, Ind., U.S.A. (March). Mimeo.

Embrapa (Empresa Brasileira de Pesquisa Agropecuária). 1989. *Avaliacao socioeconomica das pesquisas da Embrapa na Regiao Nordeste.* Embrapa-SEP Documentos No. 37. Brasilia.

Eveleens, W. M., and G. M. Scobie. 1986. Efficiency and equity in agricultural research. Paper presented to the New Zealand branch of the Australian Agricultural Economics Society Conference, July, Blenheim, New Zealand.

Evenson, R. E. 1968. The contribution of agricultural research and extension to agricultural production. Ph.D. diss., University of Chicago (August).

———. 1980. A century of productivity change in U.S. agriculture: An historical decomposition analysis. In *Research and extension productivity in agriculture,* ed. A. A. Araji, pp. 146–228. Moscow, Idaho: Department of Agricultural Economics and Applied Statistics, University of Idaho.

———. 1982. Observations on Brazilian agricultural research and productivity. *Revista de Economia Rural* 20 (July/September): 367–401.

———. 1992a. An economic impact assessment of food crop agricultural research program in Indonesia. Central Research Institute for Food Crops (CRIFC), Agency for Agricultural Research and Development (AARD), Ministry of Agriculture, Bogor, Indonesia (August). Mimeo.

———. 1994c. An *ex-ante* economic evaluation for the rice biotechnology program. Paper presented at the workshop on Rice Research Prioritization in Asia, 21–22 February, Yale University, New Haven, Conn.

———. 1996. Two blades of grass: Research for U.S. agriculture. In *The economics of agriculture.* Vol. 2, *Papers in honor of D. Gale Johnson,* ed. J. M. Antle and D. A. Sumner, pp. 171–203. Chicago: University of Chicago Press.

Evenson, R. E., and A. F. D. Avila. 1994b. Productivity change and technology transfer in the Brazilian grain sector. Yale University, Economic Growth Center, New Haven, Conn., U.S.A. (November). Mimeo.

Evenson, R. E., and E. R. da Cruz. 1992b. Economic impacts of the PROCISUR program: An international study. In *Issues in agricultural development: Sustainability and cooperation,* ed. M. A. Bellamy and B. L. Greenshields, pp. 22–28. IAAE Occasional Paper No. 6. Aldershot, U.K.: Dartmouth.

Evenson, R. E., and P. Flores. 1978a. Social returns to rice research. In *Economic consequences of the new rice technology,* pp. 243–265. Los Baños, Philippines: International Rice Research Institute.

Evenson, R. E., and D. Jha. 1973. The contribution of agricultural research system to agricultural production in India. *Indian Journal of Agricultural Economics* 28 (October/December): 212–230.

Evenson, R. E., and Y. Kislev. 1975. *Agricultural research and productivity.* New Haven, Conn., U.S.A.: Yale University Press.

Evenson, R. E., and J. W. McKinsey Jr. 1991. Research, extension, infrastructure and productivity change in Indian agriculture. In *Research and productivity in Asian agriculture,* ed. R. E. Evenson and C. E. Pray, pp. 159–184. Ithaca, N.Y., U.S.A., and London: Cornell University Press.

Evenson, R. E., P. E. Waggoner, and V. W. Ruttan. 1979. Economic benefits from research: An example from agriculture. *Science* 205 (14 September): 1101–1107.

Evenson, R. E., and F. Welch. 1978b. The impact and pervasiveness of crop and livestock improvement research in U.S. agriculture. Yale University, New Haven, Conn. Mimeo.

Evenson, R. E., E. Abdurachman, B. Hutabarat, and A. C. Tubagus. 1994a. Economic impacts of agricultural research in Indonesia. Yale University, New Haven, Conn., U.S.A. (December). Mimeo.

Farquharson, R. J. 1992. An economic evaluation of two beef cattle breeding projects. Contributed paper at the 36th Annual Conference of the Australian Agricultural Economics Society, 10–12 February, Australian National University, Canberra.

Farrell, C., and T. F. Funk. 1985. The determination of ex-ante returns to agricultural research: The case of plant biotechnology in Canada. *Canadian Journal of Agricultural Economics* 33 (March): 67–81.

Fearn, M. 1994a. *Project development assessment: Mineral elements limiting sheep production in China: Project 8911.* Economic Evaluation Unit Working Paper No. 5. Canberra: Australian Centre for International Agricultural Research (April).

Fearn, M., B. Smith, and J. S. Davis. 1994b. *Project development assessment: Pacific island pearl oyster resource development: Project 9131.* Economic Evaluation Unit Working Paper No. 6. Canberra: Australian Centre for International Agricultural Research (May).

Fearn, M., et al. 1994c. *Project development assessment: Genetic identification and stock improvement of Tilapia in Malaysia and Fiji: Project 9206.* Economic Evaluation Unit Working Paper No. 2. Canberra: Australian Centre for International Agricultural Research (March).

Fearn, M., J. S. Davis, and A. Ringrose-Voase. 1994d. Project development assessment: Project 8938: Management of clay soils for lowland rice-based cropping systems. Economic Evaluation Unit Working Paper No. 1. Canberra: Australian Centre for International Agricultural Research (March).

Finn, P. J. 1987. Evaluation of the Crop Production Development Research Program. *Canadian Farm Economics* 21 (1): 19–27.

Fishelson, G. 1968. Returns to human and research capital, United States agriculture, 1949–1964. Ph.D. diss., North Carolina State University, Raleigh, U.S.A.

Fleming, E. 1991. *Improving the feed value of straw fed to cattle and buffalo.* Economic Assessment Series No. 3. Canberra: Australian Centre for International Agricultural Research.

Flores-Moya, P., R. E. Evenson, and Y. Hayami. 1978. Social returns to rice research in the Philippines: Domestic benefits and foreign spillover. *Economic Development and Cultural Change* 26 (April): 591–607.

Fonseca, C., R. Labarta, A. Mendoza, J. Landeo, and T. S. Walker. 1996. Economic impact of the high-yielding, late-blight-resistant variety Canchan-INIAA in Peru. In *Case studies of the economic impact of CIP-related technology,* ed. T. S. Walker and C. C. Crissman, pp. 51–63. Lima, Peru: International Potato Center.

Fonseca, M. A. S., P. F. C. Araujo, and I. A. Pedroso. 1978. Retorno social aos investimentos em pesquisa na cultura do café. *Revista de Economia Rural* 16 (October/December): 31–40.

Fox, G. C., G. L. Brinkman, and N. Brown-Andison. 1987. *An Economic analysis of the returns to the Animal Productivity Research Program of Agriculture Canada from 1968 to 1984.* Guelph, Canada: Intercambio Limited (March).

Fox, G. C., A. K. E. Haque, and G. L. Brinkman. 1990. Product market distortions and the returns to federal laying-hen research in Canada: Reply and further results. *Canadian Journal of Agricultural Economics* 38 (July): 351–356.

Fox, G. C., B. Roberts, and G. L. Brinkman. 1992. Canadian dairy policy and the returns to federal dairy cattle research. *Agricultural Economics* 6 (February): 267–285.

Fuglie, K. O., and D. J. Bosch. 1995. Measuring welfare benefits from improvements in storage technology with an application to Tunisian potatoes. *American Journal of Agricultural Economics* 77 (February): 162–173.

Furtan, W. H., and A. J. Ulrich. 1987. Biotechnology and rapeseed breeding: An example of *ex-ante* evaluation of research. *Canadian Farm Economics* 21 (1): 3–17.

Garcia, H. A. 1994. Retorno social a la investigación y extensión en algodon en la República Argentina. In *La investigación agrícola en la Argentina: Impactos y necesidades de inversión,* ed. F. M. Cirio and A. J. P. Castronovo, pp. 227–239. Buenos Aires: Instituto Nacional de Tecnología Agropecuaria.

Gopinath, M., and T. L. Roe. 1996. *R&D spillovers: Evidence from U.S. food processing, farm machinery and agriculture.* Economic Development Center Bulletin No. 96-2. St. Paul, Minn., U.S.A.: University of Minnesota (October).

Griliches, Z. 1958. Research costs and social returns: Hybrid corn and related innovations. *Journal of Political Economy* 66: 419–431.

———. 1964. Research expenditure, education and the aggregate agricultural production function. *American Economic Review* 54 (December): 961–974.

Haque, A. K. E., G. C. Fox, and G. L. Brinkman. 1989. Product market distortions and the returns to federal laying-hen research in Canada. *Canadian Journal of Agricultural Economics* 37 (1): 29–46.

Herruzo, C. A. 1985. Returns to agricultural research: The case of rice breeding in Spain. *European Review of Agricultural Economics* 12 (3): 265–282.

Hertford, R., J. Ardila, A. Rocha, and C. Trujillo. 1977. Productivity of agricultural research in Colombia. In *Resource allocation and productivity in national and international agricultural research,* ed. T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, pp. 86–123. Minneapolis, Minn., U.S.A.: University of Minnesota Press.

Himes, J. 1972. The utilization of research for development: Two case studies in rural modernization and agriculture in Peru. Ph.D. diss., Princeton University, Princeton, N.J., U.S.A.

Horbasz, C. N., G. C. Fox, and G. L. Brinkman. 1988. A comparison of ex post and ex ante measures of producers' surplus in estimating the returns to Canadian federal sheep research. *Canadian Journal of Agricultural Economics* 36 (3): 489–500.

Horton, D. E., et al. 1990. Impact of agricultural research—A seed potato project in Tunisia. *Quarterly Journal of International Agriculture* 29 (January/March): 88–101.

Hossain, M. 1996. Rice research, technological progress, and impact on rural economy: The Bangladesh case. Paper presented at an international conference on the impact of rice research, Bangkok, June.

Howard, J., G. M. Chitula, and S. M. Kalonge. 1993. *The impact of investments in maize research and dissemination in Zambia.* Part I, *Main Report,* and Part II, *Annexes.* International Development Working Paper No. 39/2. East Lansing, Mich., U.S.A.: Michigan State University, Department of Agricultural Economics, Department of Economics.

Howard, J. 1994. The economic impact of improved maize varieties in Zambia. Ph.D. diss., Michigan State University, East Lansing, U.S.A.

Howard, J., and C. Mungoma. 1996. *Zambia's stop-and-go revolution: The impact of policies and organizations on the development and spread of maize technol-*

ogy. MSU International Development Working Paper No. 61. East Lansing, Mich., U.S.A.: Michigan State University, Department of Agricultural Economics, Department of Economics.

Huffman, W. E. 1974. Decision making: The role of education. *American Journal of Agricultural Economics* 56 (February): 85–97.

Huffman, W. E., and R. E. Evenson. 1989. Supply and demand functions for multiproduct U.S. cash grain farms: Biases caused by research and other policies. *American Journal of Agricultural Economics* 71 (August): 761–773.

———. 1993. *Science for agriculture: A long-term perspective.* Ames, Iowa, U.S.A.: Iowa State University Press.

Hyde, W. F., D. H. Newman, and B. J. Seldon. 1992. *The economic benefits of forestry research.* Ames, Iowa, U.S.A.: Iowa State University Press.

Irias, L. J. M., and A. F. D. Avila. 1986. Beneficios de la inversión en formación de investigadores agrarios. *Agricultura y Sociedad* (38–39): 149–158.

Ito, J. 1991. Assessing the returns of R&D expenditures on post-war Japanese agricultural production. National Research Institute of Agricultural Economics, Tokyo. Mimeo.

———. 1992. Assessing returns to R&D expenditures on post-war Japanese agricultural production. In *Issues in agricultural development: Sustainability and cooperation,* ed. M. A. Bellamy and B. L. Greenshields, pp. 14–19. IAAE Occasional Paper No. 6. Aldershot, U.K.: Dartmouth.

Jarvis, L. S., and C. Sere. 1990. Incorporating dynamic supply and demand and risk in ex-ante estimates of the return to agricultural research: The case of improved pastures for the Latin American tropics. University of California, Davis, U.S.A. (February). Mimeo.

Johnston, B. G., T. Healy, J. I'ons, and M. McGregor. 1992. *Rural research—The pay-off. The returns from research undertaken by the CSIRO Institute of Plant Production and Processing.* CSIRO Occasional Paper No. 7. Canberra: Commonwealth Scientific and Industrial Research Organisation and Australian Bureau of Agricultural and Resource Economics (May).

Johnston, J. H., and R. W. Cummings. 1991. *Control of Newcastle disease in village chickens with Oval V4 vaccine.* Economic Assessment Series No. 7. Canberra: Australian Centre for International Agricultural Research.

Joshi, P. K. and M. C. S. Bantilan. 1995. *Benefits from improved soil-water-nutrient management research: The case of groundnut production technology.* ICRISAT Socioeconomics and Policy Division Working Paper. Hyderabad, India: International Crops Research Institute for the Semi-Arid Tropics.

Kahlon, A. S., H. K. Bal, P. N. Saxena, and D. Jha. 1977. Returns to investment in research in India. In *Resource allocation and productivity in national and international agricultural research,* ed. T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, pp. 124–147. Minneapolis: University of Minnesota Press.

Karanja, D. 1990. The rate of return to maize research in Kenya: 1955–88. M.Sc. thesis, Michigan State University, East Lansing, U.S.A.

———. 1996. *An economic and institutional analysis of maize research in Kenya.* MSU International Development Working Paper No. 57. East Lansing, Mich., U.S.A.: Michigan State University, Department of Agricultural Economics, Department of Economics.

Khan, A. S., and J. S. Souza. 1991. Taxa de retorno social do investimento em pesquisa na cultura da mandioca no nordeste. *Revista de Economia e Sociologia Rural* 29 (October/December): 411–426.

Khan, M. H., and A. H. Akbari. 1986. Impact of agricultural research and extension on crop productivity in Pakistan: A production function approach. *World Development* 14 (June): 757–762.

Khatana, V. S., M. D. Upadhya, A. Chilver, and C. C. Crissman. 1996. Economic impact of true potato seed on potato production in eastern and northeastern India. In *Case studies of the economic impact of CIP-related technology,* ed. T. S. Walker and C. C. Crissman, pp. 139–156. Lima, Peru: International Potato Center.

Khatri, Y. J., and C. G. Thirtle. 1996b. Supply and demand functions for UK agriculture: Biases of technical change and the returns to public R&D. *Journal of Agricultural Economics* 47 (September): 338–354.

Khatri, Y. J., C. G. Thirtle, and J. van Zyl. 1996a. Public research and development as a source of productivity change in South African agriculture. *South African Journal of Science* 92 (3): 143–150.

Kislev, Y., and M. Hoffman. 1978. Research and productivity in wheat in Israel. *Journal of Development Studies* 14 (January): 166–181.

Klein, K. K., B. Freeze, J. S. Clark, and G. C. Fox. 1994. Returns to beef research in Canada: A comparison of time series and mathematical programming approaches. *Agricultural Systems* 46 (4): 443–459.

Klein, K. K., B. Freeze, and A. M. Walburger. 1996. Economic returns to yield-increasing research on wheat in western Canada. *Canadian Journal of Agricultural Economics* 44 (November): 207–218.

Knutson, M., and L. G. Tweeten. 1979. Toward an optimal rate of growth in agricultural production research and extension. *American Journal of Agricultural Economics* 61 (February): 70–76.

Kupfuma, B. 1994. The payoffs to hybrid maize research in Zimbabwe: An economic and institutional analysis. M.Sc. thesis, Michigan State University, East Lansing, U.S.A.

Kuroda, Y. 1996. Effects of R&D activities on rice production in Taiwan, 1976–93. Institute of Policy and Planning Sciences, University of Tsukuba, Tuskuba, Japan (10 July). Mimeo.

Laker-Ojok, R. 1994a. *The potential returns to oilseeds research in Uganda: The case of groundnuts and sesame.* MSU International Development Working Paper No. 45. East Lansing, Mich., U.S.A.: University of Michigan, Department of Agricultural Economics, Department of Economics.

———. 1994b. *The rate of return to agricultural research in Uganda: The case of oilseeds and maize.* MSU International Development Working Paper No. 42. East Lansing, Mich., U.S.A.: Michigan State University, Department of Agricultural Economics, Department of Economics.

Lanzer, E. A., I. Ambrosi, D. Dossa, L. M. M. Freire, A. F. Giroto, V. A. Hoeflich, P. Reis, V. A. Osorio, V. H. F. Porto, P. A. Salles, S. X. de Souza, and A. M. Trinidade. 1989. *Avaliacao socio-economica das pesquisas da Embrapa na Regiao Sul.* Embrapa-SEP Documentos No. 45. Brasilia: Empresa Brasileira de Pesquisa Agropecuária (Embrapa).

Leiby, J. D., and G. D. Adams. 1991. The returns to agricultural research in Maine: The case of a small northeastern experiment station. *Northeastern Journal of Agricultural and Resource Economics* 20 (April): 2–14.

Librero, A. R., and N. E. Emlano. 1990. *Estimating returns to research investment in poultry in the Philippines.* PCARD Book Series No. 88/1990. Los Baños, Philippines: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development.

Librero, A. R., and M. L. Perez. 1987a. *Estimating returns to research investment in corn in the Philippines.* PCARD Book Series No. 54/1987. Los Baños, Philippines: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (June).

Librero, A. R., M. L. Perez, and N. E. Emlano. 1987b. *Estimating returns to research investment in sugarcane in the Philippines.* PCARD Book Series No. 55/1987. Los Baños, Philippines: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development.

Lu, Y. C., L. Quance, and C. L. Liu. 1978. Projecting agriculture productivity and its economic impact. *American Journal of Agricultural Economics* 60 (December): 976–980.

Lubulwa, G. 1995e. *The human health benefits of research to reduce the hydrogen cyanide potential in cassava cultivars in Africa—A completed project assessment of ACIAR Project PN9007.* Economic Evaluation Unit Working Paper No. 21. Canberra: Australian Centre for International Agricultural Research (May).

Lubulwa, G., M. S. Arifin, W. Dodd, and J. S. Davis. 1994. *Project development assessment: The application of plant tissue culture techniques to the propagation and breeding of tea in Indonesia.* Economic Evaluation Unit Working Paper No. 14. Canberra: Australian Centre for International Agricultural Research (December).

Lubulwa, G., J. Desmarchelier, and J. S. Davis. 1995a. *Incorporating atmospheric environmental degradation in research evaluation of options for the replacement of methyl bromide.* Economic Evaluation Unit Working Paper No. 16. Canberra: Australian Centre for International Agricultural Research (February).

Lubulwa, G., S. Underhill, and J. S. Davis. 1995b. *Project development assessment: Pineapple quality improvement (PN9407).* Economic Evaluation Unit Working Paper No. 20. Canberra: Australian Centre for International Agricultural Research (May).

Lubulwa, G., D. Gwaze, J. Clarke, P. Milimo, and J. Mulatya. 1995c. *Overcoming the shortage of fuelwood and poles through forestry research: Estimates of benefits from three complete ACIAR forestry projects in Africa and Thailand.* Economic Evaluation Unit Working Paper No. 22. Canberra: Australian Centre for International Agricultural Research (June).

Lubulwa, G., B. Wafula, E. Craswell, I. Willet, and J. S. Davis. 1995d. *Dry land farming in the semi-arid tropics of Kenya: ACIAR project experience.* Economic Evaluation Unit Working Paper No. 19. Canberra: Australian Centre for International Agricultural Research (May).

Lubulwa, G., D. Gray, K. Patten, and C. Nimbkar. 1996. *Project development assessment: Prolific worm-resistant meat sheep for Maharashtra, India and Aus-*

tralia. Economic Evaluation Unit Working Paper No. 24. Canberra: Australian Centre for International Agricultural Research (July).

Lyu, S. J. L., F. C. White, and Y. C. Lu. 1984. Estimating effects of agricultural research and extension expenditures on productivity: A translog production function approach. *Southern Journal of Agricultural Economics* 16 (December): 1–8.

Macagno, L. F. 1990. The nature and distribution of gains from quality improving research in a multimarket framework: The case of barley. Ph.D. diss., University of Minnesota, St. Paul, U.S.A. (September).

Macagno, L. F., and V. L. Gomez Chao. 1994c. Impacto de la investigación en trigo en la Argentina: Un análisis económico ex-post. In *La investigación agrícola en la Argentina: Impactos y necesidades de inversión,* ed. F. M. Cirio and A. J. P. Castronovo, pp. 107–145. Buenos Aires: Instituto Nacional de Tecnología Agropecuaria (August).

Macagno, L. F., R. Munoz, and P. Luduena. 1994b. Retornos a la investigación en girasol: Impacto económico de los hibrídos en la Argentina. In *La investigación agrícola en la Argentina: Impactos y necesidades de inversión,* ed. F. M. Cirio and A. J. P. Castronovo, pp. 187–217. Buenos Aires: Instituto Nacional de Tecnología Agropecuaria (August).

Macagno, L. F., W. B. Sundquist, and D. C. Rasmusson. 1992. *Gains from agricultural research in a multimarket framework: The case of malting barley.* IR-6 Information Report No. 92-1. St. Paul, Minn., U.S.A.: University of Minnesota, Department of Agricultural and Applied Economics (January).

Macagno, L. F., J. B. Pizarro, G. H. Eyherabide, and G. Fernandez. 1994a. Retornos a la investigación en maiz: Evaluación económica de la ganancia genética en la Argentina. In *La investigación agrícola en la Argentina: Impactos y necesidades de inversión,* ed. F. M. Cirio and A. J. P. Castronovo, pp. 147–185. Buenos Aires: Instituto Nacional de Tecnología Agropecuaria (August).

MacMillan, J. A., G. Mudimu, J. F. MacRobert, L. Rugube, E. Guveya, I. T. Mutemeri, K. Chakanyuka, and B. Johnson. 1992. Measuring benefits and costs of smallholder maize extension research, Zimbabwe. University of Manitoba, Manitoba (March). Mimeo.

Makki, S. S., L. G. Tweeten, and C. S. Thraen. 1996. Returns to agricultural research: Are we assessing right? Contributed paper presented at the Conference on Global Agricultural Science Policy for the 21st Century, 26–28 August, Melbourne.

Martinez, J. C., and G. Sain. 1983. *The economic return to institutional innovations in national agricultural research: On-farm research in IDIAP Panama.* Economics Program Working Paper No. 04/83. Mexico City: International Center for the Improvement of Maize and Wheat (CIMMYT) (April).

Martinez, S., and G. W. Norton. 1986. Evaluating privately funded public research: An example with poultry and eggs. *Southern Journal of Agricultural Economics* (July): 129–140.

Mazzucato, V. 1991. Non-research policy effects on the rate of return to maize research in Kenya: 1955–1988. M.Sc. thesis, Michigan State University, East Lansing, U.S.A.

Mazzucato, V., and S. Ly. 1993. *An economic analysis of research and technology transfer of millet, sorghum, and cowpeas in Niger.* Discussion Paper No. 93-06. The Hague: International Service for National Agricultural Research (February).

McKenney, D. W., J. S. Davis, J.W. Turnbull, and S. D. Searle. 1993. Impact of Australian tree species selection research in China: An economic perspective. *Forest Ecology and Management* 60 (August): 59–76.

Mohan, R., and R. E. Evenson. 1975. The intensive agricultural districts program in India, a new evaluation. *Journal of Development Studies* 11 (April): 135–154.

Monteiro, A. 1985. Avaliação econômica da pesquisa, ensino e extensão agrícolas desenvolvidos pelo CEPLAC nos estados da Bahia e Espírito Santo no período de 1957 a 1984—Atualização. *Revista Theobroma* 15 (4): 191—206.

Moricochi, L., E. M. Neves, and P. F. C. Araujo. 1981. Pesquisa e assistência técnica no citricultura: Custos e retornos sociais. *Revista de Economia Rural* 19 (April/June): 189–203.

Morris, M. L., H. J. Dubin, and T. Pokhrel. 1994. Returns to wheat breeding research in Nepal. *Agricultural Economics* 10 (May): 269–282.

Mullen, J. D., and T. L. Cox. 1994. R&D and productivity growth in Australian broadacre agriculture. Paper presented to the 38th annual conference of the Australian Agricultural Economics Association, 7–11 February, Wellington, New Zealand.

———. 1995. The returns from research in Australian broadacre agriculture. *Australian Journal of Agricultural Economics* 39 (August): 105–128.

Mullen, J. D., and L. Stappazzon. 1996. The relationship between investment and productivity growth: Australian broadacre agriculture 1953–1994. Contributed paper for the conference on Global Agricultural Science Policy for the 21st Century, 26–28 August. Melbourne (August).

Nagy, J. G. 1984. The Pakistan agricultural development model: An economic evaluation of agricultural research and extension expenditures. Ph.D. diss., University of Minnesota, St. Paul, U.S.A.

———. 1985. The overall rate of return to agricultural research and extension investments in Pakistan. *Pakistan Journal of Applied Economics* 4 (Summer): 17–28.

Nagy, J. G., and W. H. Furtan. 1978. Economic costs and returns from crop development research: The case of rapeseed breeding in Canada. *Canadian Journal of Agricultural Economics* 26 (February): 1–14.

Newman, D. H. 1986. An econometric analysis of aggregate gains from technical change in southern softwood forestry. Ph.D. diss., Duke University, Durham, N.C., U.S.A.

Njomaha, C., A. Adamou, and A. M. Yapi. 1996. Etude d'impact de la S 35 dans l'extrême-nord Cameroun. *Etudes et recherches saheliennes* 1 (January): 9–20.

Norgaard, R. 1988. The biological control of cassava mealybug in Africa. *American Journal of Agricultural Economics* 70 (May): 366–371.

Norton, G. W. 1981. The productivity and allocation of research: U.S. Agricultural Experiment Stations: Revisited. *North Central Journal of Agricultural Economics* 3 (January): 1–12.

Norton, G. W., J. D. Coffey, and E. B. Frye. 1984. Estimating returns of agricultural research, extension, and teaching at the state level. *Southern Journal of Agricultural Economics* 16 (July): 121–128.

Norton, G. W., and C. Douglas. 1989. *Analysis of the net economic benefit of agricultural research and extension in the eastern Caribbean.* Staff Paper No. 89–8. Blacksburg, Va., U.S.A.: Virginia Polytechnic Institute and State University, Department of Agricultural Economics (January).

Norton, G. W., V. G. Ganoza, and C. Pomareda. 1987. Potential benefits of agricultural research and extension in Peru. *American Journal of Agricultural Economics* 69 (May): 247–257.

Norton, G. W., and J. Ortiz. 1991. *Reaping the return to research.* SP No. 91–6. Blacksburg, Va., U.S.A.: Virginia Polytechnic Institute and State University, Department of Agricultural Economics (January).

Norton, G. W., and R. Paczkowski. 1993. *Reaping the return on agricultural research and education in Virginia.* Information Series No. 93–3. Blacksburg, Va., U.S.A.: Virginia Polytechnic Institute and State University, College of Agriculture and Life Sciences (October).

Ojemakinde, A. 1989. Louisiana agricultural productivity: A multi-input multi-output approach. Ph.D. diss., Louisiana State University, Baton Rouge, U.S.A. (December).

Ortiz, O., J. Alcazar, W. Catalan, W. Villano, V. Cerna, H. Fano, and T. S. Walker. 1996. Economic impact of IPM practices on the Andean potato weevil in Peru. In *Case studies of the economic impact of CIP-related technology,* ed. T. S. Walker and C. C. Crissman, pp. 95–110. Lima, Peru: International Potato Center.

Otto, D. M. 1981. An economic assessment of research and extension investments in corn, wheat, soybeans and sorghum. Ph.D. diss., Virginia Polytechnic Institute and State University, Blacksburg, U.S.A.

Ouedraogo, S., and M. K. Bertelsen. 1997. The value of research on indigenous knowledge: Preliminary evidence from the case of *zai* in Burkina Faso. *Journal of Sustainable Agriculture* 10 (1): 33–42.

Ouedraogo, S., and L. Illy. 1996. Evaluation de l'impact economique des cordons pierreux: Cas du Plateau Central au Burkina Faso. Institut d'Etudes et de Recherches Agricoles, Ouagadougou, Burkina Faso (April). Mimeo.

Ouedraogo, S., L. Illy, and F. Lompo. 1995. Evaluation de l'impact economique de la recherche et la vulgarisation agricole: Cas du mais dans l'ouest du Burkina Faso. Institut d'Etudes et de Recherches Agricoles, Ouagadougou, Burkina Faso (May). Mimeo.

Page, J. R., M. N. Hunter, and W. Easdown. 1991. The economic evaluation of crop research proposals. *Australian Journal of Experimental Agriculture* 31 (6): 825–830.

Pardey, P. G., R. K. Lindner, E. Abdurachman, S. Wood, S. Fan, W. M. Eveleens, B. Zhang, and J. M. Alston. 1992. The economic returns to Indonesian rice and soybean research. Agency for Agricultural Research and Development and International Service for National Agricultural Research, Jakarta and The Hague (November). Mimeo.

Patrick, G. F., and E. W. Kehrberg. 1973. Costs and returns of education in five agricultural areas of eastern Brazil. *American Journal of Agricultural Economics* 55 (May): 145–153.

Pazols, I. F. 1981. Evaluación *ex-ante* del programa de investigación y transferencia de tecnología en arroz en Chile. M.Sc. thesis series, Publication No. 30, Universidad Cátolica de Chile, Santiago, Chile (June).

Pee, T. Y. 1977. Social returns from rubber research on peninsular Malaysia. Ph.D. diss., Michigan State University, East Lansing, U.S.A.

Penna, J. A., O. D. Vedova, and J. C. Laviero. 1994. Retorno económico de la investigación y difusión en papa en la Argentina. In *La investigación agrícola en la Argentina: Impactos y necesidades de inversión,* ed. F. M. Cirio and A. J. P. Castronovo, pp. 241–268. Buenos Aires: Instituto Nacional de Tecnología Agropecuaria.

Peterson, W. L. 1967. Return to poultry research in the United States. *Journal of Farm Economics* 49 (August): 656–670.

———. 1969. *The returns to investment in agricultural research in the United States.* Staff Paper No. P69-5. St. Paul, Minn., U.S.A.: University of Minnesota, Department of Agricultural and Applied Economics (April).

Peterson, W. L., and J. C. Fitzharris. 1977. Organization and productivity of the federal-state research system in the United States. In *Resource allocation and productivity in national and international agricultural research,* ed. T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, pp. 60–85. Minneapolis, Minn., U.S.A.: University of Minnesota Press.

Pinazza, A. H., A. C. Gemente, and S. Matsuoka. 1984. Retorno social dos recursos aplicados em pesquisa canavieira: O caso da variedade NA56–79 no estado de Sâo Paulo. *Revista de Economia Rural* 22 (January/March): 17–37.

Power, A. P., and N. P. Russell. 1988. *Economic evaluation of scientific research: A case study of the rate of return to poultry layer feeding system research.* Government Economic Service Working Paper No. 101. London: Ministry of Agriculture, Fisheries and Food.

Pray, C. E. 1978. The economics of agricultural research in British Punjab and Pakistani Punjab, 1905–1975. Ph.D. diss., University of Pennsylvania, Philadelphia.

———. 1979. The economics of agricultural research in Bangladesh. *Bangladesh Journal of Agricultural Economics* 2 (December): 1–34.

Pray, C. E., and C. F. Neumeyer. 1990. Problems of omitting private investments in research when measuring the impact of public research. In *Methods for diagnosing research system constraints and assessing the impact of agricultural research.* Vol. 2, *Assessing the impact of agricultural research,* ed. R. G. Echeverría, pp. 139–158. The Hague: International Service for National Agricultural Research (ISNAR).

Ribeiro, S. A. 1989. Private research, social benefits and public policy: The case of hybrid sorghum and pearl millet in the Indian seed industry. M.Sc. thesis, Rutgers University, New Brunswick, N.J., U.S.A.

Robinson, S., R. Kelly, N. Thompson, and B. Layman. 1995. Some pitfalls in economic evaluation. Paper presented at the 39th AAES Conference on Economic Evaluation Forum, 17 February, Perth, Australia.

Romano, L. 1988. Economic evaluation of the Colombian agricultural research system. Ph.D. diss., Oklahoma State University, Stillwater, U.S.A.

Rueda, J. L., P. T. Elwell, T. S. Walker, M. Soto, M. Bicamumpaka, and D. Berrios. 1996. Economic impact of high-yielding, late-blight-resistant varieties in the eastern and central African highlands. In *Case studies of the economic impact of CIP-related technology,* ed. T. S. Walker and C. C. Crissman, pp. 15–30. Lima, Peru: International Potato Center.

Ruiz de Londono, N., and W. Janssen. 1990. *Un caso de adopción de tecnología: La variedad de frijol Gloriabamba en Perú.* Working Paper No. 61. Cali, Colombia: International Center for Tropical Agriculture (April).

Rutten, H. 1992. *Productivity growth of Dutch agriculture.* Mededeling No. 470. The Hague: Landbouw Economisch Instituut (October).

Ryland, G. J. 1991. *Long term storage of grain under plastic covers.* Economic Assessment Series No. 8. Canberra: Australian Centre for International Agricultural Research.

Salmon, D. C. 1991. Rice productivity and returns to rice research in Indonesia. In *Research and productivity in Asian agriculture,* ed. R. E. Evenson and C. E. Pray, pp. 133–157. Ithaca, N.Y., U.S.A.: Cornell University Press.

Sanders, J. H., T. Bezuneh, and A. Schroeder. 1994. *Impact assessment of the SAFGRAD commodity networks.* Washington, D.C.: U.S. Agency for International Development (January).

Schmitz, A., and D. Seckler. 1970. Mechanized agriculture and social welfare: The case of the tomato harvester. *American Journal of Agricultural Economics* 52: 569–577.

Schwartz, L. A., J. A. Sterns, and J. F. Oehmke. 1993. Economic returns to cowpea research, extension, and input distribution in Senegal. *Agricultural Economics* 8 (February): 161–171.

Scobie, G. M., and W. M. Eveleens. 1987. *The return to investment in agricultural research in New Zealand: 1926–27 to 1983–84.* Research Report No. 1/87. Hamilton, New Zealand: Ministry of Agriculture and Food, Economics Division (October).

Scobie, G. M., and V. Jacobsen. 1992. *Allocation of R&D funds in the Australian wool industry.* Hamilton, New Zealand: University of Waikato (September).

Scobie, G. M., J. D. Mullen, and J. M. Alston. 1990. The returns to farm R&D in the Australian wool industry. Paper presented to the 34th conference of the Australian Agricultural Economics Society, 13–15 February, Brisbane.

———. 1991. The returns to investment in research on Australian wool production. *Australian Journal of Agricultural Economics* 35 (August): 179–195.

Scobie, G. M., and R. Posada. 1977. *The impact of high-yielding rice varieties in Latin America—With special emphasis on Colombia.* Cali, Colombia: International Center for Tropical Agriculture (April).

———. 1978. The impact of technical change on income distribution: The case of rice in Colombia. *American Journal of Agricultural Economics* 60 (February): 85–92.

Scobie, G. M., and R. Stewart. 1988. *Contribución económica de la investigación en la Fundación Hondureña de Investigación Agrícola (FHIA).* Research Triangle Park, N.C., U.S.A.: Sigma One Corporation (December).

Seck, P. A., M. Sidibe, and A. M. Beye. 1995. Impact social de la recherche et du transfert de technologies sur le coton au Sénégal. Institut Sénégalais de Recherche Agricole, Dakar (July). Mimeo.

Seidi, S. 1997. An economic analysis of mangrove rice research, extension and seed production in Guinea-Bissau: Preliminary evidence from the Tombali region.

Purdue University, Department of Agricultural Economics, West Lafayette, Ind., U.S.A. Mimeo.

Seré, C., and L. S. Jarvis. 1990. The betting line on beef: Ex-ante estimates of improved pasture research benefits for the Latin American tropics. In *Methods for diagnosing research system constraints and assessing the impact of agricultural research.* Vol. 2, *Assessing the impact of agricultural research,* ed. R. G. Echeverría, pp. 197–216. The Hague: International Service for National Agricultural Research (ISNAR).

Setboonsarng, S., and R. E. Evenson. 1991.Technology, infrastructure, output supply, and factor demand in Thai agriculture. In *Research and productivity in Asian agriculture,* ed. R. E. Evenson and C. E. Pray, pp. 206–216. Ithaca, N.Y., U.S.A.: Cornell University Press.

Shih, J. T., and T. T. Fu. 1993. The rate of return on investment in agricultural knowledge in Taiwan. *Industry of Free China* 80 (October): 51–64.

Sim, R. J., and A. A. Araji. 1980. The economic impact of public investment in wheat research in the western region, 1939–1974. In *Research and extension productivity in agriculture,* ed. A. A. Araji, pp. 349–415. Moscow, Idaho, U.S.A.: Department of Agricultural Economics and Applied Statistics, University of Idaho.

Smale, M., and P. W. Heisey. 1994. Maize research in Malawi revisited: An emerging success story? *Journal of International Development* 6 (November/December): 689–706.

Smith, B. L., G. W. Norton, and J. G. Havlicek Jr. 1983. Impacts of public research expenditures on agricultural value-added in the U.S. and the Northeast. *Journal of the Northeastern Agricultural Economics Council* 12 (Fall): 109–114.

Sterns, J. A., and R. H. Bernsten. 1994. *Assessing the impact of cowpea and sorghum research and extension in northern Cameroon.* MSU International Development Working Paper No. 43. East Lansing, Mich., U.S.A.: Michigan State University, Department of Agricultural Economics, Department of Economics.

Stranahan, H. A., and J. S. Shonkwiler. 1986. Evaluating the returns to postharvest research in the Florida citrus processing subsector. *American Journal of Agricultural Economics* 68 (February): 88–94.

Sumelius, J. 1987. The returns to investment in agricultural research in Finland, 1950–1984. *Journal of Agricultural Science in Finland* 59 (4): 251–354.

Sundquist, W. B., C. Cheng, and G. W. Norton. 1980. Measuring returns to Agricultural Experiment Station research expenditures for corn, wheat, and soybeans. Staff Paper No. P80-20. St. Paul, Minn., U.S.A.: University of Minnesota, Department of Agriculture and Applied Economics,(August).

Tang, A. 1963. Research and education in Japanese agricultural development I. *Economic Studies Quarterly* 13 (February): 27–41.

Thirtle, C. G., and P. Bottomley. 1988a. Is publicly funded agricultural research excessive? *Journal of Agricultural Economics* 39 (January): 99–111.

———. 1988b. Explaining total factor productivity change: Returns to R&D in UK agricultural research. Working Paper No. 88/04. Reading, U.K.: University of Reading, Department of Agricultural Economics and Management.

———. 1989. The rate of return to public sector agricultural R&D in the UK, 1965–80. *Applied Economics* 21 (August): 1063–1086.

Thirtle, C. G., J. Atkins, P. Bottomley, N. Gonese, and J. Goverch. 1992a. Agricultural research and productivity: The Green Revolution in Zimbabwe. Paper prepared for the ESRC Development Economics Study Group annual conference, March.

Thirtle, C. G., D. Hadley, and J.-C. Bureau. 1992b. Productivity comparisons and the returns to R&D in EC agriculture. Paper presented at the conference on Strengthening Endogenous Development Patterns in European Agriculture, October, Chania, Greece.

Thirtle, C. G., J. Atkins, P. Bottomley, N. Gonese, J. Goverch, and Y. J. Khatri. 1993a. Agricultural productivity in Zimbabwe. *Economic Journal* 103 (March): 474–480.

Thirtle, C. G., H. S. von Bach, and J. van Zyl. 1993b. Explaining total factor productivity growth in South African commercial agriculture, 1947–1991. Working Paper No. 93/02. Reading, U.K.: University of Reading, Department of Agricultural Economics and Management, (March). Mimeo.

Thirtle, C. G., V. E. Ball, J.-C. Bureau, R. Townsend, G. H. Peters, and D. D. Hedley. 1995. Accounting for productivity differences in European agriculture: Cointegration, multilateral TFPs and R&D spillovers. In *Agricultural competitiveness: Market forces and policy choice. Proceedings of the Twenty-Second International Conference of Agricultural Economists, Harare, Zimbabwe,* ed. G. H. Peters and D. D. Hedley, pp. 652–669. Aldershot, U.K.: Dartmouth.

Tisdell, C. A. 1991. *Culture of giant clams for food and for restocking tropical reefs.* Economic Assessment Series No. 11. Canberra: Australian Centre for International Agricultural Research.

Tobin, J. 1990. *Fruit fly control.* Economic Assessment Series No. 2. Canberra: Australian Centre for International Agricultural Research.

Traxler, G. 1990. Agronomic research and productivity growth in post–Green Revolution agriculture. Ph.D. diss., Iowa State University, Ames, U.S.A.

Traxler, G., and D. Byerlee. 1992. Economic returns to crop management research in a post–Green Revolution setting. *American Journal of Agricultural Economics* 74 (August): 574–582.

Tré, J.-P. 1995. The rates of return to mangrove rice research in West Africa. M.Sc. thesis, Purdue University, West Lafayette, Ind., U.S.A.

Ulrich, A. J., and W. H. Furtan. 1985. An investigation in the rate of return from the Canadian crop breeding program. Report prepared for the Program Evaluation Division, Agriculture Canada, Ottawa (January). Mimeo.

Ulrich, A. J., W. H. Furtan, and A. Schmitz. 1986. Public and private returns from joint venture research: An example from agriculture. *Quarterly Journal of Economics* 101 (February): 103–129.

———. 1987. The cost of a licensing system regulation: An example from Canadian prairie agriculture. *Journal of Political Economy* 95 (February): 160–178.

Unnevehr, L. J. 1986. Consumer demand for rice grain quality and returns to research for quality improvement in Southeast Asia. *American Journal of Agricultural Economics* 68 (August): 634–641.

Uyen, N. V., T. V. Ho, P. X. Tung, P. V. Zaag, and T. S. Walker. 1996. Economic impact of the rapid multiplication of high-yielding, late-blight-resistant varieties in Dalat, Vietnam. In *Case studies of the economic impact of CIP-related technology,* ed. T. S. Walker and C. C. Crissman, pp. 127–138. Lima, Peru: International Potato Center.

Wennergren, E. B., and M. D. Whitaker. 1977. Social return to U.S. technical assistance in Bolivian agriculture: The case of sheep and wheat. *American Journal of Agricultural Economics* 59 (August): 565–569.

Westgate, R. A. 1986. The economics of containerized forest tree seedling research in the United States. *Canadian Journal of Forest Research* 16 (October): 1007–1012.

White, F. C. 1995. Valuation of intangible capital in agriculture. *Journal of Agricultural and Applied Economics* 27 (December): 437–445.

White, F. C., and J. G. Havlicek Jr. 1979a. Rates of return to agricultural research and extension in the southern region. *Southern Journal of Agricultural Economics* 11 (December): 107–111.

———. 1982. Optimal expenditures for agricultural research and extension: Implications of underfunding. *American Journal of Agricultural Economics* 64 (1): 47–55.

White, F. C., J. G. Havlicek Jr., and D. M. Otto. 1979b. Fifty years of technical change in American agriculture. Paper presented at the 17th International Conference of Agricultural Economists, 3–12 September, Banff, Canada.

Widmer, L., G. C. Fox, and G. L. Brinkman. 1988. The rate of return to agricultural research in a small country: The case of beef cattle research in Canada. *Canadian Journal of Agricultural Economics* 36 (March): 23–35.

Yallah, N. 1996. Evaluation de l'impact de la recherche agronomique au Tchad: Caves du coton. Institut du Sahel, Ministère du Développement Rural, Tchad (August). Mimeo.

Yapi, A. M., A. O. Kergna, S. K. Debrah, A. Sidibe, and O. Sanogo. 1996. Analyse economique de l'impact de la recherch sur le sorgho et le mil au Mali. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bamako, Mali (December). Mimeo.

Yee, J. 1992. Assessing rates of return to public and private agricultural research. *Journal of Agricultural Economics Research* 44 (October): 35–41.

———. 1995. Is the United States really underinvesting in agricultural research? Comment. *American Journal of Agricultural Economics* 77 (November): 1048–1050.

Young, R., and M. Carter. 1990. The economic evaluation of environmental research: A case study of the south-east forests. Paper presented at the 34th annual conference of the Australian Agricultural Economics Society, 12–15 February, Brisbane.

Yrarrázaval, R., R. Navarrete, and V. Valdivia. 1982. Costos y beneficios sociales de los programas de mejoramiento varietal de trigo y maíz en Chile. In *Economía y organización de la investigación agropecuaria,* ed. M. Elgueta and E. Venezian, pp. 77–100. Santiago, Chile: Instituto de Investigaciones Agropecuarias.

Zachariah, O. E. R., G. C. Fox, and G. L. Brinkman. 1989. Product market distortions and the returns to broiler chicken research in Canada. *Journal of Agricultural Economics* 40 (January): 41–51.

Zentner, R. P. 1982. An economic evaluation of public wheat expenditures in Canada. Ph.D. thesis, University of Minnesota, St. Paul, U.S.A.

Zentner, R. P., and W. L. Peterson. 1984. An economic evaluation of public wheat research and extension expenditures in Canada. *Canadian Journal of Agricultural Economics* 32 (July): 327–354.

Julian M. Alston is a professor in the Department of Agricultural and Resource Economics, University of California, Davis. Connie Chan-Kang is a research associate in the Environment and Production Technology Division at IFPRI. Michele C. Marra is a professor in the Department of Agricultural and Resource Economics at North Carolina State University. Philip G. Pardey is a senior research fellow in the Environment and Production Technology Division at IFPRI. TJ Wyatt is an associate scientist in the Socioeconomics and Policy Program at the International Crops Research Institute for the Semi-Arid Tropics, Niamey, Niger.